Physical and physiological qualities of soybean seed as affected by processing and handling[1]

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ABSTRACT – Seed processing machines remove viable seeds from non-viable seeds and inert materials based on physical characteristics. The objective of this study was to assess the effect of each processing machine alone on the physical and physiological qualities of the soybean seeds. Seed samples of two soybean cultivars – BMX Potência RR and NK 7059 RR – were collected from five machines separately: air-screen machine, spiral separator, size grader and gravity separator. The experimental design was a completely randomized factorial, varying with the equipment, with 20 replications. Samples were assessed by germination test, accelerated aging, viability and vigor by tetrazolium test (TZ), weathering damages (TZ class 3), mechanical damages (TZ 1-8) and (TZ 6-8), stink bug damages (TZ 1-8) and weight of one thousand seeds. The air-screen machine and the spiral separator did not contribute to improve physiological quality of seeds; the size grader concentrated mechanical damages in larger sizes and stink bug damages in smaller sizes. Gravity separators showed higher quality seeds at the upper part of the machine compared to intermediate and lower parts. Mechanical damages and stink bug damages can be reduced by gravity separator and weathering damages are not eliminated by any of the machines.

Index terms: *Glycine max* (L.) Merrill, germination, vigor, mechanical damage, stink bug damage, weathering damage.

Efeito do processo de beneficiamento sobre as qualidades física e fisiológica da semente de soja

RESUMO - As máquinas de beneficiamento de sementes separam as sementes viáveis das não aptas e impurezas com base em características físicas. Objetivou-se neste trabalho avaliar o efeito de cada máquina de beneficiamento isoladamente sobre as qualidades física e fisiológica de sementes de soja. Foram retiradas amostras de duas cultivares, BMX Potência RR e NK 7059 RR, de cinco equipamentos individualmente ao longo do beneficiamento: máquina de limpeza, separador em espiral, padronizador e mesa densimétrica. O delineamento utilizado foi o inteiramente casualizado em esquema fatorial, variável com o equipamento, com 20 repetições. As amostras foram submetidas aos testes de germinação, envelhecimento acelerado, viabilidade e vigor no tetrazólio (TZ), deterioração por umidade (TZ classe 3), danos mecânicos totais (TZ 1-8), danos mecânicos letais (TZ 6-8), danos por percevejos (TZ 1-8) e massa de mil sementes. Conclui-se que a máquina de limpeza e o separador em espiral não melhoram a qualidade fisiológica das sementes de soja; o padronizador concentrou os danos mecânicos nas sementes maiores e os danos por percevejo nas sementes menores; as mesas densimétricas apresentam sementes de qualidade superior na fração alta em relação às intermediária e baixa; os danos mecânicos e os danos por percevejos podem ser reduzidos por meio da mesa densimétrica e os danos por umidade não são eliminados nem reduzidos pelos equipamentos testados.

Termos para indexação:*Glycine max* (L.) Merrill, germinação, vigor, dano mecânico, dano por percevejo, deterioração por umidade.

Introduction

The production of soybean seed of high quality depends on the use and adoption of techniques ranging from seeding to processing and storage. Therefore, in addition to decisions such as the choice of cultivars with traits that show high physiological potential and productivity (França-Neto and Krzyzanowski, 2004), it also becomes important that the design of a seed processing plant take into account machines suitable for cleaning and separation of seeds, arranged effectively, linked by transportation equipment that help to maintain or improve the initial quality of the batches received.

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The ability of the seeds processing producer in getting seeds free from inert material, from weed seeds and from other species depends largely on the arrangement, order and choice of the cleaning and separation equipment (Welch, 1973). Transport equipment (elevators and conveyor belts) must be well chosen and dimensioned as it directly affects the quality of the seeds and may increase or not the mechanical damage (Oliveira et al., 1999), affect industrial performance and allow or prevent the occurrence of mechanical mixing.

In general, for the processing of soybean seeds the following equipment are used: pre-cleaning machine, dryer, air-screen machine (cleaning machine), spiral separator, size grader and gravity separator (França-Neto et al., 2007).

The air-screen machine consists of an equipment with the basic function of cleaning the batch, whose separation is based on differences in seed size and weight and employs three separation elements: aspiration, with which the light material is removed from the seeds; defoliation, in which the good seeds pass through the screen holes, and the larger material is retained and forwarded to an outlet and screening nozzle, in which the good seed slides over the holes in the screen, while smaller particles fall through them (Vaughan et al., 1976). Buitrago et al. (1991) working with bean seeds in an air-screen machine did not find any significant improvement in the physiological and sanitary quality of them, but identified the elevation of the physical purity of the batch by the removal of larger, smaller and lighter materials.

The spiral separator consists essentially of one or more layers of metal, coiled around a single central axis vertically disposed, resembling a spiral conveyor in a vertical position. This equipment operates by gravity and separates the seeds according to their shape, density, degree of sphericity and ability to roll (Vaughan et al., 1976), removing from the seed batch those ones irregularly shaped, empty, attacked by insects or that have had their shape compromised. Lopes et al. (2011), assessing soybean seeds during processing, found no significant difference in the stage of seed processing through the spiral separator.

The size grader is an equipment composed of several flat perforated metal plates with round holes, that sorts seeds by size (width). The soybean seed varies greatly in size among different cultivars and within each cultivar. Uniformity of size in soybean seed allows the correct adjustment of the plant population in the field. With the advancement of genetic improvement and achieving higher productivity of the plants, seeding density was reduced and for lower plant populations it is necessary to be highly accurate in the distribution of seeds in the sowing row (Krzyzanowski et al., 2008). In general, the classification of soybean seeds is suggested at intervals of at least 0.5 mm and 1.0 mm maximum.

Gravity separators or gravity separator tables are equipment widely used in the seed industry, because they improve the quality when removing from the batch damaged, diseased, broken seeds, seeds attacked by insects or pathogens and other unwanted materials that are generally lighter than the suitable seeds (Peske et al., 2012). The gravity separator removes the seeds of lower density and, therefore, positively influences the physiological quality of the batch (Ahrens and Krzyzanowski, 1998). The separation of the seeds occurs in two steps: first, as these are fed on the gravity separator, they enter the air stream coming from the bottom and cross the entire porous surface of the gravity separator, stratifying the weight. The lighter seeds remain above and the heavier at the bottom, near the surface of the gravity separator. Secondly, there is the separation of these layers by a lateral movement driven by an eccentric system of propulsion, giving the gravity separator a back-and-forth move. The adjustments made to the gravity separator are loading, lateral and longitudinal inclinations, air flow, the vibration movement and fractionation of the load terminal axis. The seeds of different densities separated spouts out through the gravity separator output (Mertz et al., 2007; Nery et al., 2009; Gadotti et al., 2011; Santos-Neto et al., 2012).

This study aimed to assess the isolated influence of each equipment used during the flow of the processing on the physical and physiological quality of seed batches of two soybean cultivars.

Materials and Methods

The research was developed at the Quality Control Laboratory of Cocari in the city of Faxinal, state of Paraná, and in the Soybean Embrapa Seeds Technology Laboratory, in the city of Londrina, state of Paraná, during the year of 2011.

The seeds used in this study were obtained from two soybean cultivars: BMX Potência RR and NK 7059 RR, from the 2010/2011 harvest, being the goal of the study to compare the effect of the machines on the seeds and not the cultivars among each other.

Samples were collected from five equipment during the flow of processing alone, and they are: air-screen machine (brand Silomax, model MLSX-30), spiral separator (brand Rota, model Rota II), size grader (brand Silomax, model SXP-4X4), two gravity separators (brand Silomax, model SDS-80), being one for seeds size 6.5 mm and another for the seeds size 5.5 mm of the Seed Processing Plant of Cocari – Cooperativa Agropecuária e Industrial (Agricultural and Industrial Cooperative), in the city of Faxinal, in the state of Paraná, Brazil.

The experimental design was completely randomized for all machines assessed, with a variable factorial diagram, according to the equipment: i) air-screen machine and spiral separator (factorial 2 x 2 – two cultivars and two collection points: input and output of the machine); ii) size grader (factorial 2 x 3 – two cultivars and three collection points: input, output size 6.5 mm and output size 5.5 mm); iii) gravity separator for seeds size 6.5 mm and for seeds size 5.5 mm [factorial 2 x 5 – two cultivars and five collection points: input, output upper part (0-20 cm), output intermediate part (20-40 cm), output lower part (40-60 cm) and output disposal]; with 20 replications.

Samples of the two cultivars were collected during the passing of the seed batch in each one of the processing machines, and samples were taken before and after each machine, with 20 replications of 1 kg in each point, which became the study samples. In the sampling of each point the samples (replications) were regularly taken every 30 seconds. The sampling points of each machine are described on Table 1.

Table 1. Diagram of the points sampled on each soybean seeds processing machine in the Seeds Processing Unit of Cocari.

Equipment	Sampling points
Air-screen machine	Input
	Output
Spiral separator	Input
	Output
Size grader	Input
	Output size 6.5 mm
	Output size 5.5 mm
Gravity separator size 6.5 mm	Input
	Upper part output 0-20 cm
	Intermediate part output 20-40 cm
	Lower part output 40-60 cm
	Disposal output
Gravity separator size 5.5 mm	Input
	Upper part output 0-20 cm
	Intermediate part output 20-40 cm
	Lower part output 40-60 cm
	Disposal output

The physiological quality of the seed was assessed by the following tests: germination (Brasil, 2009); accelerated aging (Krzyzanowski et al., 1991) and tetrazolium tests (TZ) (França-Neto et al., 1998). In the tetrazolium test, in all cases were characterized the causes of loss of the seeds physiological quality: total mechanical damages (classes 1-8), lethal mechanical damages (classes 6-8), total stink bug damages (classes 1-8) and weathering damages in class 3, which represents the seeds in the last level of high vigor. The potentials of vigor, viability and types of damages were expressed as percentage. The physical quality of the seeds was assessed by measuring the weight of one thousand seeds (Brasil, 2009).

The data of the characteristics assessed were submitted to analysis of individual variance, considering the level of probability of error of 5% and additional tests for comparison of means, which were applied to the factorials 2 x 3 (Tukey's test) and 2 x 5 (Scott-Knott test), both in level of 5% of probability. Statistical analysis were performed using the computer program Sisvar (Ferreira, 2011). All factors were considered fixed effects.

Results and Discussion

The air-screen machine studied presents a set of three screens at the top, being the first one with circular perforation of size 9 mm, allowing the passing of seeds, retaining only the larger materials (green grains, pods, stems, stalks and culture debris). The material used as seeds and other impurities fall on another screen (4.0 x 22 mm oblong) with perforations smaller than the seed size (width and thickness). By going through this screen, the material smaller than the seed falls and it is collected in a discharge spout. Simultaneously occurs the aspiration operation, by which the lightweight materials are removed from the seed batch. With this, from the batches of seeds fed into the air-screen machine were removed the seeds of a size greater than 8.0 mm, which causes a decrease in the weight of a thousand seeds of the cultivar BMX Potência RR. In cultivar NK 7059 RR there was not interference of the machine on it, for this cultivar has the characteristic of having seeds of a smaller size (Table 2).

For the characteristics viability, vigor, total mechanical damages (TZ 1-8), lethal mechanical damages (TZ 6-8), stink bug damages (TZ 1-8) and weathering damages (TZ 3) presented on Table 2, it is possible to see that there was no significant difference ($p > 0.05$) by the F test for the points sampled. The sampling point factors and cultivars were unrelated to the response variables in question. For the response variables of thousand seed weight, germination and accelerated aging, the sampling point factor had a significant effect, reducing the weight of a thousand seeds and their quality. This may be due to high quality seeds being concentrated in larger sizes than those selected by the air-screen machine. The cultivar factor was significant for the weight of one thousand seeds, accelerated aging, viability, vigor, mechanical damages (TZ 1-8), stink bug damages (TZ 1-8) and weathering damages (TZ 3), showing that the cultivar BMX Potência RR presented less weight of grains and lower rates of accelerated aging, viability and vigor than cultivar

NK 7059 RR. This is also consistent with the higher results from mechanical damages (TZ 1-8) and stink bug damages (TZ 1-8) that the seeds of the cultivar BMX Potência RR presented. On the other hand, there was no dependence among the factors, only for the variable accelerated aging. There was no change in the percentage of stink bug damages, weathering damages and mechanical damages in any of the two cultivars in the two sampling sites. It is evident that the main action of the air-screen machine is a physical cleaning and a pre-selection of the material that potentially could become seed. Similar results were found by Buitrago et al. (1991) who, working with bean seeds only on machines of air-screen machine, did not show significant improvement in their physiological and sanitary qualities. Cultivar NK 7059 RR presented higher viability and vigor than the BMX Potência RR when passing by the air-screen machine, explained by the lower rates of total mechanical damages (TZ 1-8) and stink bug damages (TZ 1-8) that it had.

The passing of the seed through the spiral separator (Table 3) provided an increase in the weight value of one thousand seeds of the two cultivars, probably for having eliminated empty and malformed seeds, that reached a different speed from the round and perfect seeds. The passing through the spiral separator has improved germination, viability (TZ) and vigor (TZ) of the seeds of the cultivar BMX Potência RR, which does not occur for cultivar NK 7059 RR. The results of the accelerated aging test showed no difference among the sampled points for any of the cultivars, indicating that this test was less sensitive than the tetrazolium test to detect differences in the physiological quality of the seeds samples. In the cultivars assessed, the spiral separator did not appear effective in separating seeds attacked by stink bugs, although the cultivar BMX Potência RR presented a higher rate of stink bug damages (TZ 1-8) than the NK 7059RR. Depending on the phenological stage of the soybean plant in which the attack of stink bugs occurs, the seed damaged by the insects can not display morphological and physical characteristics differentiated enough to allow separation by the equipment. The spiral separator was not effective either in reducing the rate of mechanical damages (TZ 1-8) and (TZ 6-8) nor on the weathering damages (TZ 3) in any of the cultivars studied.

Carvalho and Nakagawa (2012) state that the seeds of higher weight, because of being better nourished during their development, have well formed embryos with higher reservations, therefore being stronger, resulting in more developed seedling. The seed vigor, however, depends not only on the potential for development of the seed in the field. Table 4 presents the results of the assessments of the seeds produced by each size, collected at the exits of the size grader. It was possible to see differences in weight of one thousand seeds, where the seeds retained in the 5.5 mm screen are of 22% (cultivar BMX Potência RR) and 20% (cultivar NK 7059 RR) lighter than the ones retained in the 6.5 mm screen. The results of germination and accelerated aging of the seeds size 6.5 mm are greater than the results of size 5.5 mm for both cultivars. The viability (TZ) and the vigor (TZ) are higher in the seeds size 6.5 mm regarding the ones size 5.5 mm for cultivar NK 7059 RR. In the cultivar BMX Potência RR the viability did not change the input for the outputs of the two screen of the size grader and the vigor (TZ) was superior for the seeds size 6.5 mm compared to size 5.5 mm after passing by the size grader. Pádua et al. (2010), working with three soybean cultivars, observed that larger seeds were superior in germination and accelerated aging tests and they also gave rise to taller and more productive plants. The cultivar BMX Potência RR always presented values of the weights of one thousand seeds smaller than the ones of cultivar NK 7059 RR in the input and output of the size grader.

It is noted that the seeds of the cultivar BMX Potência RR, classified as of higher size (6.5 mm) were the ones that showed the highest concentration of lethal mechanical damages (TZ 6-8), although this has not necessarily been reflected in the vigor levels studied. This indicates that the vigor attribute does not depend exclusively on the development process of the plant in the field, but also in the management in the harvest and processing of the seeds (Krzyzanowski et al., 1991). Both cultivars had the total mechanic damages (TZ 1-8) incremented for the seeds of size 6.5 mm, again showing that there was a concentration of this kind of damage in the larger seeds. This results are consistent with Krzyzanowski et al. (1991) who, assessing soybeans seeds classified by size and its seedling and quality precision, found rates of higher mechanical damages in larger seeds, being such damages from the seeds harvest process. They also found that there was no prejudicial effect to the processing operation in the seeds quality in three years of study. Nonetheless, Silva et al. (2011), found harmful effects caused by the processing of soybean seed due to the large number of bucket elevators existing in the Seed Processing Plant they studied.

The stink bug damages (Table 4) concentrated in the seed size 5.5 mm for both cultivars and the percentage of weathering damages (TZ Class 3) of the seeds did not change after being stratified by size by size grader. Most seeds damaged by stink bugs are concentrated on smaller seeds batches because both the nymphs and the adult insects get their food by the bite of the plant tissue and subsequent suction of the cellular content of plant parts and seeds, making them smaller, wrinkled and seedless (Corrêa-Ferreira and Azevedo, 2002).

Table 2. Mean values of the weight of one thousand seeds (g), germination (%), accelerated aging (%), viability (TZ 1-5) (%), vigor (TZ 1-3) (%), total mechanical damages (TZ 1-8) (%), lethal mechanical damages (TZ 6-8) (%), total stink bug damages (TZ 1-8) (%) and weathering damages (TZ 3) (%) of the seeds of two cultivars of soybeans removed at the input and output of the air-screen machine, in 2010/2011 harvest.

Points			Weight of one thousand seeds			Germination (%)			Acelerated aging (%)		
			Cultivars			Cultivars			Cultivars		
			BMX Potência RR	NK 7059RR		BMX Potência RR	NK 7059RR		BMX Potência RR	NK 7059RR	Mean
Input			162.63 Ab	168.67 Aa		89.50 Aa	87.95 Ab		84.60	88.40	86.50 A
Output			157.30 Bb	167.80 Aa		86.60 Bb	88.95 Aa		81.35	86.10	83.72 B
Mean									82.98 b	87.25 a	
Variation sources	Points (P)	1	192.2000*			18.0500*			154.0125*		
	Cultivars (C)	1	1,367.8580*			3.2000^{ns}			365.5125*		
	P x C	1	99.0125*			76.0500*			4.5125^{ns}		
	Residue	76	3.3312			4.3382			6.3151		
			CV (%) = 1.11	General Mean = 164.09		CV (%) = 2.36	General Mean = 88.25		CV (%) = 2.95	General Mean = 85.11	

Points			Viability TZ (%)			Vigor TZ (%)			Mechanical damages (TZ 1-8) (%)		
			Cultivars			Cultivars			Cultivars		
			BMX Potência RR	NK 7059RR	Mean	BMX Potência RR	NK 7059RR	Mean	BMX Potência RR	NK 7059RR	Mean
Input			84.50	86.65	85.57 A	60.20	64.70	62.45 A	26.45	20.80	23.62 A
Output			83.95	87.00	85.47 A	58.55	65.45	62.00 A	24.75	19.95	22.35 A
Mean			84.23 b	86.83 a		59.38 b	65.08 a		25.60 a	20.38 b	
Variation sources	Points (P)	1	0.2000^{ns}			4.0500^{ns}			32.5125^{ns}		
	Cultivars (C)	1	135.2000*			649.8000*			546.0125*		
	P x C	1	4.0500^{ns}			28.8000^{ns}			3.6125^{ns}		
	Residue	76	13.9539			26.7803			14.8796		
			CV (%) = 4.37	General Mean = 85.52		CV (%) = 8.32	General Mean = 62.22		CV (%) = 16.78	General Mean = 22.99	

Points			Mechanical damages (TZ 6-8) (%)			Stink bug damages (TZ 1-8) (%)			Weathering damages (TZ 3) (%)		
			Cultivars			Cultivars			Cultivars		
			BMX Potência RR	NK 7059RR	Mean	BMX Potência RR	NK 7059RR	Mean	BMX Potência RR	NK 7059RR	Mean
Input			10.30	10.05	10.17 A	19.85	13.90	16.87 A	16.55	21.15	18.85 A
Output			9.05	9.30	9.17 A	19.25	14.30	16.77 A	15.95	19.65	17.80 A
Mean			9.68 a	9.68 a		19.55 a	14.10 b		16.25 b	20.40 a	
Variation sources	Points (P)	1	20.0000^{ns}			0.2000^{ns}			22.0500^{ns}		
	Cultivars (C)	1	0.0000^{ns}			594.0500*			344.4500*		
	P x C	1	1.2500^{ns}			5.0000^{ns}			4.0500^{ns}		
	Residue	76	8.3461			14.6618			9.5132		
			CV (%) = 29.86	General Mean = 9.67		CV (%) = 22.76	General Mean = 16.82		CV (%) = 16.83	General Mean = 18.32	

Means followed by equal uppercase letters in the column and lowercase letters on the line do not differ by the F test (≤ 0.05). *Significant; ^{ns}Non significant by the F test (≤ 0.05).

Table 3. Mean values of the weight of one thousand seeds (g), germination (%), accelerated aging (%), viability (TZ 1-5) (%), vigor (TZ 1-3) (%), total mechanical damages (TZ 1-8) (%), lethal mechanical damages (TZ 6-8) (%), total stink bug damages (TZ 1-8) (%) and weathering damages (TZ 3) (%) of the seeds of two cultivars of soybeans removed at the input and output of the spiral separator, in 2010/2011 harvest.

Points		Weight of one thousand seeds (g)			Germination (%)			Accelerated aging (%)		
		Cultivars			Cultivars			Cultivars		
		BMX Potência RR	NK 7059RR		BMX Potência RR	NK 7059RR		BMX Potência RR	NK 7059RR	Mean
Input		159.70 Bb	167.27 Ba		89.80 Ba	90.00 Aa		82.90	87.75	85.32 A
Output		163.54 Ab	168.96 Aa		91.40 Aa	89.55 Ab		83.15	86.90	85.02 A
Mean								83.03 b	87.33 a	
Variaton sources										
Points (P)	1	152.6281*			6.6125^{ns}			1.8000^{ns}		
Cultivars (C)	1	843.0511*			13.6125^{ns}			369.8000*		
P x C	1	23.2201*			21.0125*			6.0500^{ns}		
Residue	76	1.6629			4.1967			6.6303		
		CV (%) = 0.78	General Mean = 164.86		CV (%) = 2.27	General Mean = 90.18		CV (%) = 3.02	General Mean = 85.17	

Points		Viability TZ (%)		Vigor TZ (%)		Mechanical damages (TZ 1-8) (%)	
		Cultivars		Cultivars		Cultivars	
		BMX Potência RR	NK 7059RR	BMX Potência RR	NK 7059RR	BMX Potência RR	NK 7059RR
Input		84.00 Bb	86.65 Aa	59.85 Bb	67.70 Aa	21.65 Ba	18.85 Aa
Output		88.70 Aa	87.80 Aa	74.80 Aa	70.20 Ab	24.95 Aa	17.50 Ab
Variaton sources							
Points (P)	1	171.1125*		1,522.5125*		19.0125^{ns}	
Cultivars (C)	1	15.3125^{ns}		52.8125^{ns}		525.3125*	
P x C	1	63.0125*		775.0125*		108.1125*	
Residue	76	9.3678		24.7520		20.3033	
		CV (%) = 3.53	General Mean = 86.78	CV (%) = 7.30	General Mean = 68.13	CV (%) = 21.73	General Mean = 20.73

Points		Mechanical damages (TZ 6-8) (%)			Stink bug damages (TZ 1-8) (%)			Weathering damages (TZ 3) (%)		
		Cultivars			Cultivars			Cultivars		
		BMX Potência RR	NK 7059RR	Mean	BMX Potência RR	NK 7059RR	Mean	BMX Potência RR	NK 7059RR	Mean
Input		9.40	9.10	9.25 A	18.50	13.20	15.85 A	14.40	21.05	17.72 A
Output		7.50	8.90	8.20 A	21.00	12.65	16.82 A	12.20	21.70	16.95 A
Mean		8.45 a	9.00 a		19.75 a	12.93 b		13.30 b	21.38 a	
Variaton sources										
Points (P)	1	22.0500^{ns}			19.0125^{ns}			12.0125^{ns}		
Cultivars (C)	1	6.0500^{ns}			931.6125*			1.304.1125*		
P x C	1	14.4500^{ns}			46.5125^{ns}			40.6125^{ns}		
Residue	76	7.9131			51.3257			14.6467		
		CV (%) = 32.24	General Mean = 8.72		CV (%) = 43.85	General Mean = 16.33		CV (%) = 22.07	General Mean = 17.33	

Means followed by equal uppercase letters in the column and lowercase letters on the line do not differ by the F test (≤ 0.05). *Significant; ^{ns}Non significant by the F test (≤ 0.05).

Table 4. Mean values of the weight of one thousand seeds (g), germination (%), accelerated aging (%), viability (TZ 1-5) (%), vigor (TZ 1-3) (%), total mechanical damages (TZ 1-8) (%), lethal mechanical damages (TZ 6-8) (%), total stink bug damages (TZ 1-8) (%) and weathering damages (TZ 3) (%) of the seeds of two cultivars of soybeans removed at the input and output of the size grader, in 2010/2011 harvest.

Points			Weight of one thousand seeds (g)		Germination (%)			Accelerated aging (%)		
			Cultivars		Cultivars			Cultivars		
			BMX Potência RR	NK 7059RR	BMX Potência RR	NK 7059RR		BMX Potência RR	NK 7059RR	Mean
Input			163.54 Bb	168.96 Ba	91.40 Aa	89.55 Aa		83.15	86.90	85.02 B
Output 6.5			187.90 Ab	193.85 Aa	92.15 Aa	89.70 Ab		86.10	88.55	87.32 A
Output 5.5			147.35 Cb	155.05 Ca	87.65 Ba	87.85 Ba		82.50	84.65	83.57 C
Mean								83.92 b	86.70 a	
Variation sources	Points (P)	2		16,048.8018*	118.0583*			143.0333*		
	Cultivars (C)	1		1,212.2163*	56.0333*			232.4083*		
	P x C	2		14.3506*	19.3083*			7.2333^{ns}		
	Residue	114		1.3960	3.9614			5.5145		
	CV (%) = 0.70		General mean = 169.44		CV (%) = 2.22	General mean = 89.71		CV (%) = 2.75	General mean = 85.30	

Points			Viability TZ (%)		Vigor TZ (%)			Mechanical damages (TZ 1-8) (%)		
			Cultivars		Cultivars			Cultivars		
			BMX Potência RR	NK 7059RR	BMX Potência RR	NK 7059RR	Média	BMX Potência RR	NK 7059RR	Mean
Input			88.70 Aa	87.80 Aa	74.80	70.20	72.50 A	24.95	17.50	21.22 B
Output 6.5			86.65 Aa	88.05 Aa	70.10	69.10	69.60 B	26.90	21.50	24.20 A
Output 5.5			87.85 Aa	84.75 Bb	66.85	64.00	65.42 C	22.85	18.65	20.75 B
Mean					70.58 a	67.77 b		24.90 a	19.22 b	
Variation sources	Points (P)	2	38.1000*		505.9750*			139.8583*		
	Cultivars (C)	1	22.5333^{ns}		238.0083*			969.0083*		
	P x C	2	50.6333*		32.4083^{ns}			27.0083^{ns}		
	Residue	114	10.6421		25.0048			26.5425		
	CV (%) = 3.74		General mean = 87.30		CV (%) = 7.23	General mean = 69.17		CV (%) = 23.36	General mean = 22.05	

Points			Mechanical damages (TZ 6-8) (%)		Stink bug damages (TZ 1-8) (%)			Weathering damages (TZ 3) (%)		
			Cultivars		Cultivars			Cultivars		
			BMX Potência RR	NK 7059RR	BMX Potência RR	NK 7059RR		BMX Potência RR	NK 7059RR	Mean
Input			7.50 Ba	8.90 Aa	21.00 Aa	12.65 ABb		12.20	21.70	16.95 A
Output 6.5			9.90 Aa	9.80 Aa	14.75 Ba	11.55 Bb		14.35	22.25	18.65 A
Output 5.5			7.15 Bb	11.00 Aa	19.70 Aa	15.30 Ab		14.45	20.80	17.62 A
Mean								13.67 b	21.58 a	
Variation sources	Points (P)	2	27.2583*		219.2250*			18.2250^{ns}		
	Cultivars (C)	1	88.4083*		848.0083*			1,880.2083*		
	P x C	2	39.7583*		72.6083*			24.8083^{ns}		
	Residue	114	7.9504		15.8039			10.5776		
	CV (%) = 31.19		General mean = 9.04		CV (%) = 25.12	General mean = 15.82		CV (%) = 18.45	General mean = 17.62	

Means followed by equal uppercase letters in the column and lowercase letters on the line do not differ by the Turkey test ($p \leq 0.05$) and F test ($p \leq 0.05$), respectively.
*Significant; ^{ns}Non significant by the F test (≤ 0.05).

On the gravity separators, the seeds of greater weight and higher physiological quality concentrated in the top positions of output, presenting a decrease of quality as the seeds migrated to the lower parts (Tables 5 and 6). This results are consistent with Amaral et al. (2012) who, separating canola seeds by density, also stratified the physiological quality. Regarding the weight of one thousand seeds for the cultivar BMX Potência RR in both sizes, there was no differentiation as to the weight in three tracks sampled (0-20, 20-40 and 40-60 cm) in relation to the input values. For the seeds of cultivar NK 7059 RR, there was an increase in the weight in the first two tracks (0-20 and 20-40 cm) in relation to the entry, already showing a value of less than the entry in the range 40-60 cm for both sizes. This demonstrates the efficiency of the gravity separator in the separation by specific weight within the same size seeds. Similar results were found by Fessel et al. (2003) with corn seeds. Although the germination and the viability (TZ 1-5) of both cultivars have been similar for the gravity separator for size 6.5 mm (Table 5), cultivar NK 7059 RR presented results of higher vigor (TZ 1-3) and accelerated aging and this data is explained by the lower rates of total mechanic damages (TZ 1-8) and stink bug damages (TZ 1-8) of the cultivar.

The percentage of germination for the cultivar BMX Potência RR was already presented high at the moment of feeding the gravity separator (89.95% for size 6.5 mm and 87.1% for size 5.5 mm) and kept stable and high in all tracks of seed output, only decreasing in the fraction that was intended for disposal (83.25% of size 6.5 mm and 79.6% in size 5.5 mm). Cultivar NK 7059 RR also presented high initial germination results (90.7% for size 6.5 mm and 88.15% for size 5.5 mm), but had a more differentiated stratification between the tracks. In size 6.5 mm, cultivar NK 7059 RR kept the germination constant, with a slight fall in the range 40-60 cm, when it presented 88.9%, still a satisfactory result for soybeans. In size 5.5 mm the seed quality stratification of cultivar NK 7059 RR was more gradual and decreasing along the tracks. These results indicate that the gravity separator is efficient as an equipment of effective improvement of the physical and physiological quality of seed lots. Similar results in studies with gravity separators were also found for seeds of several other species (Alexandre and Silva, 2000; Fantinatti et al., 2002; Mertz et al., 2007; Nery et al., 2009; Gadotti et al., 2011; Santos-Neto et al., 2012).

The results of accelerated aging, viability (TZ) and vigor (TZ) (Tables 5 and 6) were reduced for both cultivars to the extent that the seeds were removed from the bottoms of the gravity separator for the two sizes. Similar results were found by Gadotti et al. (2006) in seeds of broccoli sprouts.

In gravity separator, seeds size 6.5 mm (Table 5) showed a reduction of the total mechanical damages (TZ 1-8) for both cultivars in the two highest points on the separator: 0-20 cm and 20-40 cm. For smaller seeds, 5.5 mm (Table 6), no separation was possible among samples for cultivar BMX Potência RR with respect to total mechanical damages (TZ 1-8). For cultivar NK 7059 RR, the level of mechanical damages was kept stable up to point 40-60 cm, when there was an increase of this damage at the point of disposal. However, when lethal mechanical damages are observed (TZ 6-8) for the two cultivars, it appears that there was a better separation of them by the two gravity separators, starting with the lowest rates in the upper separator and remaining stable or growing as they approached the lower part of the separator. It was observed that the rate of the mechanical damages of the seeds in the discarding fractions of both cultivars was larger and visually it became apparent that these fractions contained more seeds with cracked seed coats. These results explain the improvement of physiological quality that the gravity separator gives to the seed lot.

The results of stink bugs damages (TZ 1-8) allowed the stratification for both cultivars, and in the separator for the seed size 6.5 mm the rate decreased from 11.97% (input) and decreased to 11.15% at point 20-40 cm. From point 40-60 cm there was an increase of this kind of damage by the effect of its concentration in the seeds of lower density that went out of the lower part of the separator.

Seeds size 5.5 mm of both cultivars showed similar behavior with regard to stink bug damages (TZ 1-8) after passing through the gravity separator. The percentage of seeds with these types of damage remained stable from input point 20-40 cm, increasing from point 40-60. These results indicate that the gravity separator, regardless of the size of the seeds, was effective in the stratification of the lots, for the stink bug damages. Seeds attacked by insects, depending on the severity of the attack, may maintain the same shape and the same dimensions as the not attacked, but are lighter due to the partial or total destruction within (Vaughan et al., 1976). This information, coupled with the good operation of the gravity separator, can be instrumental in improving the quality of lots with this kind of problem.

Weathering damages (TZ 3) were not eliminated or reduced by any of the gravity separators for cultivar BMX Potência RR. Cultivar NK 7059 RR showed mixed results in different sampling points at the gravity separators, probably originating from the sampling effect, because this kind of damage does not give any physical characteristic that can be separated by the processing machines. Weathering damages are of great importance for the soybean seeds, as they evolve during storage and decrease the seed physiological potential (Moreano et al., 2011; Forti et al., 2010).

Table 5. Mean values of the weight of one thousand seeds (g), germination (%), accelerated aging (%), viability (TZ 1-5) (%), vigor (TZ 1-3) (%), total mechanical damages (TZ 1-8) (%), lethal mechanical damages (TZ 6-8) (%), total stink bug damages (TZ 1-8) (%) and weathering damages (TZ 3) (%) of the seeds of two cultivars of soybeans removed at the input and output of the gravity separator for size 6.5 mm, in 2010/2011 harvest.

Points		Weight of one thousand seeds (g)			Germination (%)			Accelerated aging (%)		
		Cultivars			Cultivars			Cultivars		
		BMX Potência RR	NK 7059RR		BMX Potência RR	NK 7059RR	Mean	BMX Potência RR	NK 7059RR	
Input		187.58 Bb	195.19 Ba		89.95	90.70	90.32 A	84.65 Bb	88.35 Ba	
0 - 20 cm		189.23 Ab	197.21 Aa		90.80	90.60	90.70 A	85.75 Ab	91.45 Aa	
20 - 40 cm		188.87 Ab	196.99 Aa		90.45	90.40	90.42 A	85.90 Ab	91.60 Aa	
40 - 60 cm		188.67 Ab	193.41 Ca		88.95	88.90	88.92 B	84.25 Bb	87.65 Ba	
Disposal Output		186.38 Cb	191.10 Da		83.25	82.90	83.07 C	78.05 Cb	81.40 Ca	
Mean					88.68 a	88.70 a				
Variation sources: Points (P)	4		128.2663*			413.0700*			538.9425*	
Cultivars (C)	1		2,198.5081*			0.0200^{ns}			954.8450*	
P x C	4		30.4627*			1.8200^{ns}			15.0325*	
Residue	190		0.7042			5.5326			5.4866	
		CV (%) = 0.44	General mean = 191.46		CV (%) = 2.65	General mean = 88.69		CV (%) = 2.73	General mean = 85.90	

Points		Viability TZ (%)			Vigor TZ (%)			Mechanical damages (TZ 1-8) (%)		
		Cultivars			Cultivars			Cultivars		
		BMX Potência RR	NK 7059RR	Mean	BMX Potência RR	NK 7059RR	Mean	BMX Potência RR	NK 7059RR	Mean
Input		86.75	87.30	87.02 B	63.00	70.75	66.87 B	29.65	21.70	25.67 A
0 - 20 cm		89.40	89.25	89.32 A	68.10	74.85	70.05 A	27.45	19.25	23.35 B
20 - 40 cm		88.05	90.00	89.02 A	67.50	72.00	71.17 A	31.20	18.70	24.95 B
40 - 60 cm		85.35	85.00	85.17 C	57.35	67.00	62.17 C	30.50	21.10	25.80 A
Disposal Output		81.60	82.10	81.85 D	53.45	62.00	57.72 D	31.15	23.70	27.42 A
Mean		86.23 a	86.73 a		61.88 b	69.32 a		29.99 a	20.89 b	
Variation sources: Points (P)	4		380.0800*			1,262.5500*			87.3325*	
Cultivars (C)	1		12.5000^{ns}			2,767.6800*			4,140.5000*	
P x C	4		8.1250^{ns}			46.8800^{ns}			41.2625^{ns}	
Residue	190		8.9926			28.9400			20.9600	
		CV (%) = 3.47	General mean = 86.48		CV (%) = 8.20	General mean = 65.60		CV (%) = 18.00	General mean = 25.44	

Points		Mechanical damages (TZ 6-8) (%)			Stink bug damages (TZ 1-8) (%)			Weathering damages (TZ 3) (%)		
		Cultivars			Cultivars			Cultivars		
		BMX Potência RR	NK 7059RR	Mean	BMX Potência RR	NK 7059RR	Média	BMX Potência RR	NK 7059RR	
Input		10.40	10.60	10.50 C	13.25	10.70	11.97 B	15.30 Ab	20.80 Aa	
0 - 20 cm		7.40	7.95	7.67 D	12.30	8.60	10.45 C	16.70 Ab	19.30 Ba	
20 - 40 cm		8.55	8.15	8.35 D	14.00	8.30	11.15 C	15.95 Ab	22.40 Aa	
40 - 60 cm		10.95	12.80	11.87 B	15.15	10.45	12.80 B	16.30 Ab	18.80 Ba	
Disposal Output		14.90	15.10	15.00 A	16.75	13.15	14.95 A	14.30 Ab	17.55 Ba	
Mean		10.44 a	10.92 a		14.29 a	10.24 b				
Variation sources: Points (P)	4		345.8175*			121.1700*			55.5325*	
Cultivars (C)	1		11.5200^{ns}			820.1250*			824.1800*	
P x C	4		7.0325^{ns}			14.3000^{ns}			32.5175*	
Residue	190		6.7926			12.2682			9.8637	
		CV (%) = 24.40	General mean = 10.68		CV (%) = 28.56	General mean = 12.26		CV (%) = 17.70	General mean = 17.74	

Means followed by equal uppercase letters in the column and lowercase letters on the line do not differ by the Scott-knott test ($p \leq 0.05$).
*Significant; ^{ns}Non significant by the F test (≤ 0.05).

Table 6. Mean values of the weight of one thousand seeds (g), germination (%), accelerated aging (%), viability (TZ 1-5) (%), vigor (TZ 1-3) (%), total mechanical damages (TZ 1-8) (%), lethal mechanical damages (TZ 6-8) (%), total stink bug damages (TZ 1-8) (%) and weathering damages (TZ 3) (%) of the seeds of two cultivars of soybeans removed at the input and output of the gravity separator for size 5.5 mm, in 2010/2011 harvest.

Points			Weight of one thousand seeds (g)		Germination (%)		Accelerated aging (%)		
			Cultivars		Cultivars		Cultivars		
			BMX Potência RR	NK 7059RR	BMX Potência RR	NK 7059RR	BMX Potência RR	NK 7059RR	Mean
Input			146.73 Bb	152.62 Ca	87.10 Aa	88.15 Ba	83.30	87.35	85.32 B
0 - 20 cm			148.59 Ab	155.96 Aa	87.05 Ab	89.85 Aa	85.40	88.75	87.07 A
20 - 40 cm			148.15 Ab	153.48 Ba	87.45 Aa	88.25 Ba	84.95	87.65	86.30 A
40 - 60 cm			147.90 Ab	149.62 Da	87.30 Aa	85.90 Ca	81.15	82.00	81.57 C
Disposal output			146.70 Ab	149.51 Da	79.60 Bb	81.20 Da	77.90	79.40	78.65 D
Mean							82.54 b	85.03 a	
Variation sources	Points (P)	4		110.4557*	436.1450*		507.7325*		
	Cultivars (C)	1		1,068.1442*	47.0450*		310.0050*		
	P x C	4		53.3136*	23.4950*		17.2175^{ns}		
	Residue	190		0.8664	5.7292		8.2945		
	CV (%) = 0.62		General mean = 149.92		CV (%) = 2.78	General mean = 86.18	CV (%) = 3.44	General mean = 83.78	

Points			Viabilidade TZ (%)		Vigor TZ (%)		Mechanical damages (TZ 1-8) (%)	
			Cultivars		Cultivars		Cultivars	
			BMX Potência RR	NK 7059RR	BMX Potência RR	NK 7059RR	BMX Potência RR	NK 7059RR
Input			85.30 Bb	88.20 Aa	57.80 Bb	71.50 Aa	20.85 Aa	14.50 Cb
0 - 20 cm			89.20 Aa	89.30 Aa	66.00 Aa	68.60 Aa	21.20 Aa	14.20 Cb
20 - 40 cm			88.50 Aa	86.55 Aa	66.00 Aa	66.55 Aa	21.15 Aa	14.95 Cb
40 - 60 cm			87.40 Aa	83.85 Bb	64.05 Aa	65.85 Aa	22.95 Aa	17.70 Bb
Disposal output			84.65 Ba	79.25 Cb	57.00 Ba	55.90 Ba	23.50 Aa	22.50 Aa
Variation sources	Points (P)	4		297.5175*	743.6500*		214.9125*	
	Cultivars (C)	1		124.8200*	616.0050*		1,331.2800*	
	P x C	4		103.7575*	344.0050*		57.9925*	
	Resíduo	190		14.5811	49.2487		21.0979	
	CV (%) = 4.43		General mean = 86.22		CV (%) = 10.98	General mean = 63.92	CV (%) = 23.74	General mean = 19.35

Points			Mechanical damages (TZ 6-8) (%)		Stink bug damages (TZ 1-8) (%)			Weathering damages (TZ 3) (%)		
			Cultivars		Cultivars			Cultivars		
			BMX Potência RR	NK 7059RR	BMX Potência RR	NK 7059RR	Mean	BMX Potência RR	NK 7059RR	Mean
Input			9.05 Aa	7.70 Ca	20.05	14.55	17.30 B	14.40	19.00	16.70 A
0 - 20 cm			7.35 Ba	6.30 Ca	19.30	15.00	17.15 B	14.30	17.00	15.65 B
20 - 40 cm			7.20 Ba	8.50 Ba	19.35	14.80	17.07 B	16.00	19.55	17.77 A
40 - 60 cm			7.50 Bb	9.90 Ba	20.15	16.95	18.55 A	15.15	16.75	15.95 B
Disposal output			9.90 Ab	15.00 Aa	22.25	17.10	19.67 A	16.65	18.10	17.37 A
Mean					20.22 a	15.68 b		15.30 b	18.08 a	
Variation sources	Points (P)	4		183.0825*	51.6375*			32.7575*		
	Cultivars (C)	1		81.9200*	1,030.5800*			386.4200*		
	P x C	4		70.4825*	7.8675^{ns}			17.6825^{ns}		
	Residue	190		9.8353	15.4258			11.4874		
	CV (%) = 35.48		General mean = 8.84		CV (%) = 21.88	General mean = 17.95		CV (%) = 20.31	General mean = 16.69	

Means followed by equal uppercase letters in the column and lowercase letters on the line do not differ by the Skott-knott test ($p \leq 0.05$).

*Significant; ^{ns}Non significant by the F test (≤ 0.05).

Conclusions

The air-screen machine studied does just a physical cleaning and a pre-selection of the seed batch, not contributing to the improvement of the physiological quality;

The spiral separator assessed is not efficient in the separation of seeds attacked by stink bugs nor contributes to the improvement of the seeds physiological quality;

The size grader shows the concentration of mechanical damage to larger size seeds and stink bug damages in smaller size seeds;

Soybean seeds exited in the upper zone of the gravity separator present physical and physiological qualities significantly higher than the seeds exited in the intermediate and lower parts;

The gravity separator is effective in reducing soybean seeds with mechanical damages and stink bug damages;

None ot the equipments used during processing were not effective in removing soybean seeds with weathering damages.

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