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Optimization of millet (*Penissetum glaucum*) seed processing using a gravity table

Otimização do processamento de sementes de milheto (Penissetum glaucum) empregando mesa de gravidade

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ABSTRACT: Millet (*Pennisetum americanum*) is a species cultivated for multiple purposes that presents high adaptability to different growing environments. The frequent occurrence of low quality seed lots is one of the limiting factors for this crop. Thus, the objective of this work was to evaluate the physical and physiological quality of millet seeds processed by gravity table. A batch of millet seeds (cultivar BRS 1501) was processed on a triangular gravity table. Samples were collected at different points along the equipment discharge zone (upper, upper middle, lower intermediate and disposal sections) and in the feed silo (initial batch). After processing and collection, the physical and physiological quality of the seed samples was evaluated. The results showed that the processing of millet seeds by gravity table separates the seeds by density/weight, with the heavier ones generally being of better physiological quality, facilitating the separation of batches with different quality, resulting in efficient seed separation of different sizes and weights. The processing of millet seeds by gravity table improves the physical and physiological quality of seed lots.

Keywords: *Pennisetum americanum*; Seeds; Postharvest; Physiological quality.

RESUMO: O milheto (*Pennisetum americanum*) é uma espécie cultivada com múltiplas finalidades que apresenta alta adaptabilidade a diferentes ambientes de cultivo. A frequente ocorrência de lotes de sementes de baixa qualidade é um dos fatores limitantes para esta cultura. Assim, o objetivo deste trabalho foi avaliar a qualidade física e fisiológica de sementes de milheto processadas por mesa de gravidade. Um lote de sementes de milheto (cultivar BRS 1501) foi processado em mesa de gravidade triangular. As amostras foram coletadas em diferentes pontos ao longo da zona de descarga do equipamento (seções superior, média superior, intermediária inferior e de descarte) e no silo de alimentação (lote inicial). Após o processamento e coleta, avaliou-se a qualidade física e fisiológica das amostras de sementes. Observou-se com os resultados que o processamento de sementes de milheto por mesa de gravidade, a mesma separa as sementes por densidade/peso especifico, facilitando a separação de lotes com qualidade diferente, resultando em uma separação eficiente de sementes de diferentes tamanhos e pesos. O processamento de sementes de milheto por mesa de gravidade melhora a qualidade física e fisiológica dos lotes de sementes.

Palavras-chave: *Pennisetum americanum*; Sementes; Pós-colheita; Qualidade fisiológica.

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INTRODUCTION

Millet (*Pennisetum americanum*) is a forage crop originated from Africa. It was introduced to Brazil in the late 1970s and, since then, have been grown as soil cover crop (nutrients recycling), raw forage associated with biofortification, conserved forage (silage), and for grain production for animal feed (Vendruscolo *et al*., 2017; Ceballos *et al*., 2018; Dias-Martins *et al*., 2018; Ortas; Yucel, 2020; Gaoh *et al*., 2023). The plant has a vigorous root system, a high nutrient absorption capacity, and great adaptability to different environments, including those with low fertility soils, water deficit, and high temperatures (Negarestani *et al*., 2019; Sharma *et al*., 2021; Bani Hani *et al*., 2022; Shrestha *et al*., 2023).

However, some factors still limit the development of the crop, such as the low quality of commercial seed lots (Javorski *et al*., 2018; Costa *et al*., 2021). In this sense, the improvement of millet seed processing needs special attention, as it is a step for removing impurities and for possible physical improvement of seed lots (Noor *et al*., 2018; Bernardi *et al*., 2019; Geisen *et al*., 2021).

Separating undesired materials from high-quality seeds is necessary during the seed processing. Seed size (width, thickness, and length) shape, tegument or pericarp texture, color, affinity to water, electrical conductivity, and specific mass are parameters used to qualify the seed production. Considering these parameters, specific mass is the most important for seed enhancement focused on improving the physical quality of the lot due to the direct correlation of seed specific mass with physiological quality (Medici *et al*., 2018; Kumar *et al*., 2020; Dumanoglu *et al*., 2022; Marasca *et al*., 2022), This separation is carried out usinga gravity table. Seeds at different developmental stages, malformed, damaged by insects, or infected by microorganisms differ in specific mass and, therefore, are discarded (Srinivas, 2022).

Gravity table has proven to be efficient for enhancing seed lots of different species. Seed lots processed using gravity table present higher germination index and vigor due to the removal of foreign materials and defective or undersized seeds, promoting a better seedling emergence in the field (Gadotti *et al*., 2020; Macedo *et al*., 2020). Nonetheless, when seeds are put on a gravity table without previous standardization by size, as usually done for commercial production of millet seeds, the presence of different physical attributes, as weight, size, and density of the kernels, makes the separation of lower density kernels more complex and, consequently, results in lower physiological quality (Gadotti *et al*., 2020). Thus, the objective of this article was to evaluate the physical and physiological quality of millet seeds processed by gravity table.

2 MATERIAL AND METHODS

The experiment was conducted at the Federal University of Pelotas, in Capao do Leao, Rio Grande do Sul, Brazil. The seed lots used were from the millet cultivar BRS 1501, produced in the state of Rio Grande do Sul in the 2014-2015 crop season. The seeds were subjected to a cleaning process with the aid of a sieve and a fan before the improvement of the lots by the gravity table; only whole seeds, without impurity and with adequate size, were placed on the gravity table, as done for commercial production of millet seeds.

The experiment was performed using a triangular gravity table, specific to process small-sized seeds (SPH 4603,00; Seed Processing Holland). The gravity table performance in processing millet seeds was evaluated by collecting samples from the gravity table discharge zone for qualitative analysis. The gravity table discharge zone was separated into four points: upper, upper middle, lower middle, and discard (Figure 1). Seed samples were collected from the inside of the feed inlet of the gravity table to classify the lot without the effect of the equipment (initial lot). The gravity table was set according to the characteristics of the lot to be processed; the discard percentage in the gravity table was 4.6% of the total seeds processed.

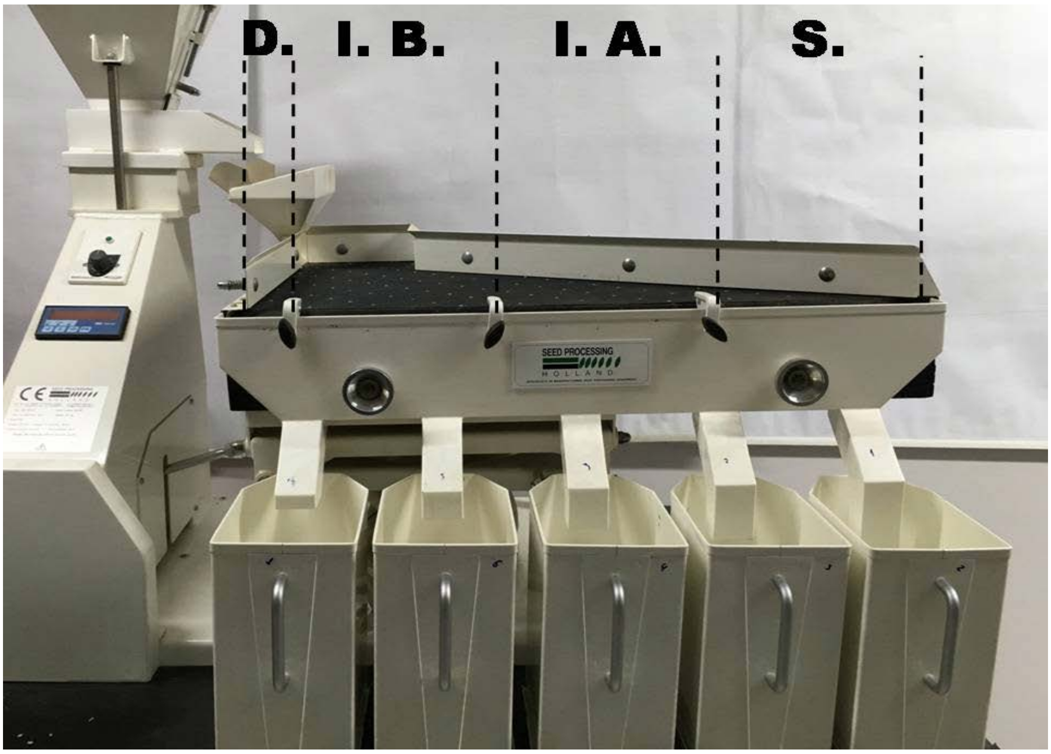

Figure 1. Millet seed collection points (D. =discard; I.B =lower middle; I.B = upper middle; and S. = upper) on the gravity table to evaluate the effect of the gravity table on the physical and physiological quality of the seeds.

Seed samples were collected at different points while the millet seeds lots were processed on the gravity table. Randomized complete block experimental design with four blocks was used. The sampling was carried out simultaneously for all collection points in each block. After the sample collection, the physical and physiological quality of the seeds were evaluated. The physical parameters evaluated were:1.000^{-seed} weight, actual density, density, and retention in sieve mesh. It was carried out by randomly choosing eight sub-samples of 100 seeds and measuring their weights (grams), according to the Brazilian Rules for Seed Analysis (Brasil, 2009).

Sub-samples of 200 seeds were weighed in an analytic precision balance. The seeds were then immersed in a known oil volume and the volume shift was established by the difference between the initial and final volumes. The actual seed sample density was evaluated by dividing the seed weight by the shifted volume. Two sub-samples of 200 seeds were used for each collected sample; the results were expressed in gdm^{-3} (Moreira et al., 1985).

The bulk density was established by weighing a known volume of seeds and dividing the result by its volume. Two sub-samples were used for each collected sample; the results were expressed in g dm^{-3}. Two 20-gramsub-samples of millet seeds were passed through a sequence of round sieves with decreasing mesh pore diameters: 2.5, 2.2, 2.0, 1.8, and 1.5 mm. The results were expressed in weight percentage of sample retained in the sieves over the initial sample weight (Peske; Filho; Barros, 2019).

Physiological quality analysis was based on germination rate, first germination count, length of the seedling and its parts, dry matter weight of the seedling and its parts, emergence, and emergence speed index. Four sub-samples of 50 seeds were used for each collected sample. The seeds were placed on germination paper substrate (Germitest), previously moistened with water using twice the weight of the dry paper, and kept at temperature of 25 °C. The evaluations were carried out seven days after seeding, according to the RAS; the results were expressed as percentages of normal seedlings. Percentage of normal seedlings was evaluated three days after seeding, for the germination test (Brasil, 2009).

An imaginary line was longitudinally drawn on the upper third part of the germination paper to determine the lengths of the seedling and its parts. The substrate was previously moistened with an amount of distilled water equivalent to twice the paper dry weight. Twenty millet seeds were then placed on the paper with the micro pyle facing the lower part of the paper. The germitest paper rolls were placed vertically in the germinator for three days at 25 °C in the dark. The total length of the seedlings, including the shoot and roots, was measured using a ruler (mm). The radicle of the seedlings, which was considered in the seedling length, was separated from the aerial part and its dry matter weighting g plant^{-1} was measured after drying in an oven at 70 °C until constant weight (Brasil, 2009).

The emergence test was performed using 200 seeds per sample collected from the gravity table discharge zone, which were divided into two sub-samples of 100 seeds; a row of100 millet seeds were sown in trays to a depth of 1 command irrigated daily as needed. The final seedling emergence was evaluated28 days after seeding; the results were expressed as percentages of emerged seedlings. Emerged seedlings were daily counted after seeding in the trays. The emergence speed index was calculated according to Maguire (1962).

The data collected were subjected to analysis of variance for each physical and physiological parameter. Mean values of the different collection points were compared using the Duncan test at 5% probability. Statistical analyses were performed using the R software (R Core Team, 2014).

3 RESULTS AND DISCUSSION

Considering the physical quality parameters, the collection point had significant effect on density and 1.000^{-seed} weightand no effect on actual density (Table 1). The gravity table separated millet seeds lots with different densities. Seed samples collected at the upper and upper middle points of the gravity table discharge zone showed higher density (10%) than samples collected at the discard point (Table 1). The result showed that there was an improvement of the seed lot by using the gravity table, denoting a high efficiency in separating lower-density seeds.

Table 1. Physical characteristics of millet seed samples collected at different points of the gravity table discharge and at the feed inlet

Collection Point	Density (g dm^{-3})	Actual density (g dm^{-3})	1.000-seed weight (g)
Initial Lot	812.5 a	1336.7^{ns}	6.964 b
Upper	808.9 a	1327.7	9.003 a
Upper Middle	800.5 ab	1341.5	7.085 b
Lower Middle	790.0 b	1279.7	7.027 b
Discard	730.9 c	1329.1	4.359 c
Mean	788.5	1322.9	6.887
Coefficient of variation(%)	1.4	6.2	3.4

Means followed by the same letter in the columns are not significantly different from each other by the Duncan test.

Differences in densities of 5% and 14% were found between the upper and lower points of the discharge zone for soybean and rice, respectively, denoting that the gravity table effectively separated high-quality seeds lots (Almeida *et al*., 2016; Soares *et al*., 2021). However, seed samples collected at the upper point showed similar density to those collected from the initial lot. This result may be due to a better mixture of seeds of different sizes inside the container used for density evaluation.

The seed samples collected at the upper point showed uniformity and large seeds, resulting in a larger space among seeds in the container used for density evaluation (Table 2). Moreover, seed samples collected from the initial lot showed higher variation in seed size, which enables abettor fitting of smaller seeds among spaces between larger seeds (Table 2).

The actual density of millet seed presented no variation for the collection point soft the gravity table, denoting that the gravity table did not efficiently separate seeds with different densities. It can be explained by the fact that smaller seeds, which weigh less, are moved to the upper layer of the seed bulk and driven to the gravity table discard point, similar to low-density seeds. The density of these seeds maybe high, but they have low sizes and low total weight; thus, they are discarded by the gravity table as low-density seeds, whereas the opposite is true for larger and heavier seeds (Table 1, 2). Therefore, high- and low-density seeds are found evenly in all processed seed mass. Possibly, seeds previously selected by size should be used for processing millet seeds on gravity table to improve the efficiency in separating seeds with different densities.

However, seed density is used to efficiently regulate the gravity table to process seeds of many crops. It has shown a high correlation with seed physiological quality; thus, the gravity table can increase the physiological quality of seed lots, even when the processed seeds are not previously selected by size (Melo *et al*., 2018; Macedo *et al*., 2020; Gadotti *et al*., 2020).

Table 2. Percentage of retention percentages of millet seed samples in sieve mesh, collected at different discharge points of the gravity table discharge and at the feed inlet

Collection Point	Sieve mesh diameter					
	< 1.5 mm	1.5 mm	1.8 mm	2.0 mm	2.2 mm	> 2.5 mm
Initial Lot	2.1 d	5.8 b	17.1 bc	46.4 a	25.3 b	4.3 bc
Upper	0.1 e	0.4 d	4.8 d	43.0 b	44.9 a	7.7 a
Upper Middle	2.4 c	3.0 c	16.8 c	47.7 a	26.7 b	3.3 c
Lower Middle	2.9 b	5.5 b	18.6 b	43.8 b	24.7 b	4.8 b
Discard	9.6 a	16.7 a	30.8 a	29.1 c	9.9 c	1.0 d
Mean	3.4	6.3	7.6	42.4	26.3	4.2
Coefficient of variation (%)	4.0	13.9	5.6	3.2	9.3	16.4

Means followed by the same letter in the columns are not significantly different from each by the Duncan test.

The gravity table separated millet seed lots by seed size. Samples collected at the upper point presented the lowest percentage of small seeds (seeds retained in the 1.5^{-mm} and 1.8^{-mm} diameter meshes and seeds smaller than 1.5 mm) and a higher percentage of large seeds (seeds retained in the 2.0^{-mm} and 2.2^{-mm} diameter meshes). The seed samples collected at the middle lower and discard points presented a higher percentage of small seeds and lower percentage of large seeds. Physical attributes such as seed size and 1.000^{-seed} weight were significantly affected by the collection point on the gravity table. However, different millet seed lots presented different responses due to size variation and 1.000^{-seed} weight; these attributes occasionally present no effect on millet seed vigor (Costa *et al*., 2021; Martinatti *et al*., 2021). This indicates that factors other than seed weight and size, such as seed density used in these studies, may have affected the physiological results of seed lots.

The collection point on the gravity table had significant effects on all evaluated variables related to seed physiological quality (Table 3). The germination of seeds collected at the discard point was approximately 20% lower than that of seeds collected at the upper and upper middle points. The germination of seeds collected at the middle lower point and from the initial lot was approximately15% higher than that of seeds collected at the discard point (Table 3). These results show that the gravity table separates seeds that cannot develop the germination process and form a normal seedling under ideal conditions for its development. Moreover, millet seeds processed by gravity table present increases in germination percentage.

Table 3. Physiological characteristics of millet seed samples collected at different points of the gravity table discharge and at the feed inlet

Collection Point	Germination (%)	First germination count (%)	Emergence (%)	Emergence speed index
Initial Lot	82 b	73 a	61 ab	44,7 ab
Upper	89 a	75 a	73 a	58,2 a
Uppermiddle	87 ab	75 a	54 b	30,5 bc
Lower middle	83 b	70 b	48 b	24,7 bc
Discard	70 c	61 b	46 b	19,29 c
Mean	82	70	56	35,5
Coefficient of variation (%)	4.7	6.8	18.1	38.67

Means followed by the same letter in the columns are not significantly different from each by the Duncan test.

The results of the first germination count indicated that seeds collected at the upper and upper middle points present fast growth of embryos that can develop and form normal seedlings under ideal environmental conditions in a short time. Furthermore, the emergence speed index of seedlings showed the higher vigor of seeds collected at the upper point, compared to those collected at other points of the gravity table discharge. In addition, the emergence percentage of seedlings from seeds collected at the upper point was 30% higher than that of seeds collected at the discard point (Tables 3).

According to the results from first germination count, germination speed, and emergence, seed lots with higher physiological quality showed higher field performance than those with low physiological quality. Production fields of different cultivated species grown from high physiological quality seeds show fast and uniform emergence; excellent plant characteristics; higher initial plant development; and plants with larger leaf areas, plant heights, and dry matter production, resulting in higher uniformity of plants and yields (Moreano *et al*., 2018; Drumond *et al*., 2019). These features are important for millet crops, regardless its purpose (grain production, forage, or soil coverage); the use of seeds with high physiological quality results in high gains for all potential uses of the crop.

The benefits of processing millet seeds by gravity table were observed through their seedling growth. The gravity table separated seed lots with superior seedling growth (Table 4). The total shoot and root lengths of millet seedlings were higher for seedlings from seeds collected at the upper and upper middle points. Seedlings developed from seeds collected at the middle lowe rand discard points and non-processed seeds on the gravity table presented approximately 20% lower growth rates, corroborating the seedling length data, denoting that the dry matter production was affected by seed processing on the gravity table.

Table 4. Total length (TL), shoot length (APL), root length (RL), total dry weight (TDM), shoot dry weight (APDM), and root dry weight (RDM) of millet seedlings from seeds collected at different points of the gravity table discharge and at the feed inlet

Collection Point	TL (cm)	APL (cm)	RL (cm)	TDM (mg)	APDM (mg)	RDM (mg)
Initial Lot	15.44 b	4.54 b	10.9 b	25.2 b	16.7 bc	8.5 bc
Upper	19.04 a	5.98 a	13.06 a	31.2 a	21.6 a	9.5 ab
Uppermiddle	19.02 a	6.12 a	12.90 a	30.3 a	19.6 ab	10.7 a
Lower middle	15.15 b	4.39 b	10.75 b	23.9 b	15.7 c	8.1 bc
Discard	15.97 b	4.71 b	11,25 b	17.1 c	10.6 d	6.6 c
Mean	16.92	5.15	11.77	25.6	16.85	8.71
Coefficient of variation (%)	5.4	7.35	7.11	11.18	13.22	15.45

Means followed by the same letter in the columns are not significantly different from each by the Duncan test.

Seeds collected at the upper point showed higher dry matter production than seeds collected at the lower point of the gravity table discharge. Seeds collected at the upper point presented approximately 80% higher dry matter production than seeds collected at the discard point. In the field, this result represents a fast, uniform, and suitable amount of dry matter to be used as animal feed or as soil coverage and protection. The shoot and root dry weights presented similar results to total dry matter production, maintaining the proportions among the different seedling parts (Table 4).

The growth and dry matter production of seedlings from seeds collected at the upper point of the gravity table discharge were connected to the higher physiological performance of the seeds. The seed lots separated by gravity table presented superior 1.000$^{\text{-seed}}$ weight and large seed sizes, which have higher photoassimilate accumulation during their formation. Seeds with higher amounts of reserves were separated possibly due to their higher enzyme activity, which is key to degradation of reserve tissues, as the alpha-amylase in millet seeds (Cavalcante *et al*., 2018; Oliveira *et al*., 2019). High physiological quality seeds present higher capability to convert macromolecules from reserve tissues into simpler molecules and transport them to the embryo for its nutrition, development, and formation of new essential structures for a healthy plant development in the field (Shibata *et al*., 2020). According to Smolikova *et al*. (2020), seeds with high performance and with low deterioration indexes better maintain the integrity of the membrane system; therefore, membrane selectivity and organelle activity, which are essential for the unfolding of reserve macromolecules, increase the embryo growth strength and, thus, seedling growth and dry matter production.

The processing of millet seeds by gravity table results in gains of approximately 30%. in seed physiological performance Therefore, gravity table is indispensable for obtaining physiologically superior millet seed lots, by initially separating seeds with higher weights and large sizes, featuring high reserve contents. In addition, these seeds showed development of embryos, as shown by the first germination count and the emergence speed index. The viability of the seed lots, evaluated by germination, is a significant aspect to be considered (Oliveira *et al*., 2020).

Therefore, the seeds processed by the gravity table showed superior physiological quality, resulting in seedlings with high emergence and growth rates and enhanced field performance, which are features that rural producers can explore.

4 CONCLUSIONS

The processing of millet seeds by gravity table improves the physical and physiological quality of seed lots. Seeds with low physiological quality are discarded during seed processing on gravity table.

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