Multivariate Statistical Analysis Applied to Physical Properties of Soybean Cultivars in The Design and Regulation of Post-Harvest Equipment

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Research Article

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Abstract

The present work had as aim to evaluate the similar of soybean cultivars according to physical properties as a guiding parameter for decision making in the design and regulation of post-harvest equipment using multivariate analysis. First, Pearson's correlation coefficients were estimated. Posteriorly, principal component analysis was performed to verify the interrelationship between variables and soybean cultivars. A biplot was built with the first two principal components. Finally, a boxplot was built for each variable considering the grouping presented by the analysis of main components. By principal component analysis, we identified the formation of two clusters (G1 and G2) of cultivars. Unit specific mass was the physical property that most contributed to the formation of G1, while the other physical properties contributed to the formation of G2. Soybean cultivars comprising the G1 are more similar to each other only for unit specific mass, and the cultivars allocated in group G2 are more similar for all the other properties evaluated. These results are recommended by the equipment manufacturing industry and the seed processing units to carry out projects and equipment adjustments to efficiently manage the post-harvest of soybean seeds.

Introduction

Soybean cultivation has significantly expanded over the last three decades. In the 2018/2019 crop season, there was an estimated production of 3,385 thousand tons of grain in a cultivated area of 35,150.2 thousand hectares[1]. One of the factors increasing grain yield is the use of precision agriculture techniques and the adaptation of different soybean cultivars to producing regions.

Soybean genetic breeding has contributed to the development of a large number of cultivars. In Brazil, until May 2011, 823 soybean cultivars were listed in the National Register of Cultivars, of which 502 conventional cultivars and 321 transgenic cultivars were available. In January 2018, the National Register of Cultivars recorded an increase of 118% in the number of cultivars compared to 2011, including 1234 transgenic and 565 conventional cultivars, totaling 1799 registered cultivars[1].

Different soybean genetic materials have impacted post-harvest operations, mainly due to physical seed variations. The technological advance with the genetic improvement and the appearance of different soybean seed cultivars generated a great variability of soybean seed lots with different physical characteristics, making it necessary, for greater operational yield in the post-harvest units, reduction of losses and gains in quality, the development of flexible equipment in terms of regulations and controls, considering the different groups of physical characteristics of seed cultivars[2–5].

The composition and geometric shapes of seeds often interfere with the design, sizing, and regulation of machines for handling, drying, storage, processing, and sowing[2,3]. The knowledge of the physical seed properties is important for designing the harvesting systems; determining the static capacity of the silos and the conveyor belts; the size of the hoppers, ducts and discharge ramps, fans, drying and aeration systems, and sieves; separation and classification, processing, handling, and storage[4,5].

Physical factors interfering with post-harvest homogenization of seed include water content, which requires reduction for storage conditions to minimize mass respiration processes and stored seed deterioration[6]. Storage conditions associated with seed water content may promote an increase in seed respiratory intensity[6,7]. This causes physical and chemical changes, making seeds inappropriate for sowing. Reduction in seed water content through the drying process interferes with physical properties such as porosity, specific mass, and seed volume[7,8].

The volume of seeds is most varied during drying, often reducing in size or geometric shape, which may compromise post-harvest operations. Indeed, when poorly sized, machines can cause physical damage, cracks, and seed breaks, making the quality of the seeds unfeasible, especially with regards to germination[9]. Studies evaluating physical seed properties in several crops have reported that the homogenization of seed lots by size ensures better post-harvest operation performance and seed conservation and quality[8–11].

Considering the different characteristics of seeds of soybean cultivars and the different post-harvest operations and equipment, the present study aimed to evaluate the similar of seed cultivars according to physical properties as a guiding parameter for decision making in the design and regulation of post-harvest equipment using multivariate statistical analysis.

Materials And Methods

4.1 Genetic material and physical properties of seeds assessed

This study was carried out at the Post-Harvest Laboratory of Agricultural Products of the Federal University of Santa Maria, Campus Cachoeira do Sul-RS, Institute of Support to Agricultural Research in Chapadão do Sul - Chapadão Foundation, in partnership with the Federal University of Mato Grosso do Sul, Campus of Chapadão do Sul-MS, Brazil.

The study characterized physical properties of soybean seeds from forty genetically modified cultivars: 68H0 RSF IPRO, 6968 RSF RR, 7166 RSF, 3980 RR, 6139 RR, ATRIA RR, GURIA RR, MAMBA RR, BRS 73 RR, 2728 IPRO, CD 2687 RR, 2737 RR, CZ26 B42 IPRO, FLECHA IPRO, 7148 IPRO, 8372 IPRO, 8573 RR, IPRO EXTRA, CERTA IPRO, ULTRA IPRO, KWS RK 6813 RR, KWS RK 6813 RR, M7739 IPRO, 5947 IPRO, 7337 RR, M6410, NS 7007 IPRO, NS 6823 RR, NS 7505 IPRO, DESAFIO, TMG 1180 GX RR, TMG 7062 IPRO, 8473 RR, TMG 1264 RR, 98Y30, 98Y52, 96Y90, 8579 RSF, 2686 IPRO, NS 7447.

The evaluated seeds come from heterogeneous lots produced and sown in the central-western region of Brazil as a means to adjust equipment designed for post-harvest operations, as shown in Figure 1.

Two hundred soybean seeds of each sample (three repetitions) were collected at three different points on the packages (top, middle, and bottom) to measure the physical seed properties in the harvests of 2017, 2018 and 2019. In total were evaluated three hundred and thirty and six lots of soybean seeds cultivars. The seed size was determined by measuring the length, width, and thickness of the seed by using a 0.01 mm resolution caliper, while the other physical properties were calculated using the equations in Table 1[12].

4.2 Statistical analysis

To evaluate the results, the analysis of variance was performed, comparing the means by the Tukey test at 5% probability, using the Sisvar 5.6 software to define the largest seeds, intermediate-larger seeds, intermediate-smaller seeds, and smaller seeds. Next, Pearson's correlation coefficients were estimated to verify the association between spray relative deposition and VIs. We use the correlation network to graphically express the results. In this procedure, green lines link variables with positive correlation and red lines join negatively correlated variables. The line thickness is proportional to the magnitude of the correlation. Posteriorly, principal component analysis was performed to verify the interrelationship between variables and soybean cultivars. A biplot was built with the first two principal components due to the ease of interpretation of these results. In this biplot, two clusters were defined to use the k-means algorithm, which groups treatments whose centroides are closest until there is no significant variation in the minimum distance of each observation to each centroid. Finally, a boxplot was built for each variable considering the grouping presented by the analysis of main components. These analyzes were performed with the aid of the "qgraph", "ggfortify" and "ggplot2" packages from software R.

Results

Table 2 shows the average physical property evaluations of forty soybean seed cultivars. The axis corresponding to seed length averaged 8.116 mm, with variations of 9.300 mm from cultivar FLECHA IPRO to 7.040 mm for cultivar NS 7447. The average seed width was 7.464 mm, with variations of 8.180 mm from cultivar FLECHA IPRO to 6.620 mm for cultivar NS 7447. Seed thickness presented average values of 6.890 mm, with variations of 7.900 mm from cultivar FLECHA IPRO to 6.175 mm for cultivar NS 6823 RR.

The average seed volume was 219.447 mm³, with variations of 314.515 m³ from cultivar FLECHA IPRO to 159.230 mm³ for cultivar TMG 1180GX RR. Seed roundness averaged 0.920, with 0.994 variations from cultivar CZ26 B42 IPRO to cultivar 1180GX RR with 0.835. The average sphericity of the seeds was 0.903, with 0.983 variations of cultivar NS 7447 to 0.839 of cultivar KWS RK 6813 RR2. The average equivalent diameter of the seeds was 7.321 mm, with variations of 8.261 mm of cultivar FLECHA IPRO to 6.599 mm for cultivar TMG 1180GX RR.

The projected area of seed cultivars had average values of 47.65 mm², with variations of 59.71 mm² from cultivar FLECHA IPRO to 36.58 mm² for cultivar NS 7447. The surface area of seed cultivars had a mean value of 168.62 mm², ranging from 214.27 mm² for FLECHA IPRO cultivar to 136.73 mm² for the TMG 1180GX RR cultivar. The surface-volume-ratio averaged 0.773, ranging from 0.834 for 2686 IPRO to 0.681 for FLECHA IPRO. The friction coefficient as a function of seed displacement averaged 1.147, and it ranged from 1.902 for cultivar 6139 RR to 0.650 for cultivar M6410.

The average resting angle was 23.08°, ranging from 28.68° from cultivar KWS RK 6813 RR2 to 20.32° for cultivar 8473 RR. The average unit mass of seeds was 0.186 g, ranging from 0.251 g of cultivar FLECHA IPRO to 0.115 g of cultivar TMG 1180GX RR. The unit-specific mass of the seeds presented an average of 1030.67 kg m^{-3}, ranging from 1649.155 kg m^{-3} of cultivar KWS RK 6813 RR to 813.679 kg m^{-3} of cultivar 6139 RR. The average apparent specific mass for soybean cultivars was 718.70 kg m^{-3}, ranging from 783.030 kg m^{-3} to 598.723 kg m^{-3} of cultivar FLECHA IPRO for cultivar 8473 RR, respectively. The average porosity of seed mass was 39.20%, ranging from 43.83% of cultivar MAMBA RR to 36% of cultivar 8473 RR.

According to Table 3, the seed lots of the different cultivars present variability in their physical properties, which were possible to characterize in groups of larger seeds (LS), intermediate-larger seeds (ILS), intermediate-smaller seeds (ISS), smaller seeds (SS). Among the groups, there was a predominance of ILS seeds, followed by LS, ISS and SS. Soybean seed cultivars have heterogeneous physical characteristics that are distinguishable between FLECHA IPRO, 6139 RR and MAMBA RR cultivars from larger seeds, and NS 7447, 2686 IPRO and 8473 RR cultivars from smaller seeds, while the other cultivars prevailed as seeds of size averages.

The cultivar UNIGEL 8473 RR Desafio had greater differentiation in apparent specific mass and porosity, while the cultivar KWSRK 6813 RR achieved greater differentiation for physical properties of unit specific mass and angle of repose. In the evaluation of the unit mass, the cultivar FLECHA IPRO differed from all other cultivars, except the cultivars NS 6823 RR and TMG 1180GX RR which were similar between them and with FLECHA IPRO. The cultivar AVANTSEED 96139 RR obtained greater differentiation with the other cultivars for the physical property coefficient of friction.

The cultivar AVANTSEED SMANBA RR had higher differentiation for porosity. Given the importance of uniformity of seed lots for optimal regulation of postharvest equipment, in a research realized with three soybean cultivars, separating them by size in to improve sowing quality and grain distribution. In the evaluation of the physical properties length, width, sphericity it was observed that the seed cultivar UNIGEL NS 7447 differed from the other cultivars, while for the physical properties thickness, volume, equivalent diameter, projected area, surface area and area ratio, however for the surface/volume the highest differentiation occurred with cultivar FLECHA IPRO, however, for the physical property circularity, cultivar M7739 IPRO stood out.

By Pearson’s correlation network Figure 2, it can be noted a high positive correlation between VxPA, VxED, VxSA, EDxSA, EDxW, WxV, PAxL, PAxW, and LxV. Moderate positive correlations were verified between LxED, EDxT, TxV, and CrxSp. On the other hand, there were high negative correlations between WxSVR, PAxSVR, VxSVR, EDxSVR, SVRxSA, and moderate negative correlations between SVRxL, SVRxT, CrxFC, SpxFC, USMxW, USMxPA, and USMxEd. The other correlations had low magnitude, and for this reason, they were not mentioned here. From these results, it is possible to infer about the positive relationship between the size-related properties volume, length, width, projected and surface areas, equivalent diameter, and thickness, while these variables showed low or no correlation with the other physical properties of the seed, such as those related to shape and mass.

Figure 3 shows the results obtained by principal component analysis, which revealed the existence of two clusters (G1 and G2). Cluster 1 (G1) was formed by the cultivars 3980 RR, 6139 RR, CERTA IPRO, KWS RK 6813 RR2, KWS RK 6813 RR, M7739 IPRO, 5947 IPRO, 7337 RR, TMG 1180 GXRR, TMG 1264 RR, 98Y30, 98Y52, 96Y90, 8579 RSF, 2686 IPRO, and NS 7447. In turn, the cultivars 68H0 RSF IPRO, 6968 RSF RR, 7166 RSF, ATRIA RR, GURIA RR, MAMBA RR, BRS 7380 RR, 2728 IPRO, 2687 RR, 2737 RR, CZ26 B42 IPRO, FLECHA IPRO, GXM 7148 IPRO, GXM 8372 IPRO, 8573 RR, 74178 IPRO EXTRA, ULTRA IPRO, M6410, NS 7007 IPRO, NS 6823 RR, NS 7505 IPRO, DESAFIO, TMG 7062 IPRO, and 8473 RR constituted the cluster 2 (G2). Unit specific mass (USM) was the physical property that most contributed to the formation of G1. This finding is supported by the boxplot of physical properties, where it can be noted a marked difference between clusters for USM, for which cluster G1 showed higher means (Figure 4). The surface-to-volume ratio (SVR) and friction coefficient (FC) were the other properties for which G1 showed means higher than G2, however, they did not contribute to the formation of G1 by the PCA. The other physical properties contributed to the formation of G2. In Figure 3, it can be verified that G2 showed higher means for length (L), width (W), thickness (T), volume (V), circularity (Cr), sphericity (Sp), equivalent diameter (ED), projected and surface areas (PA and SA, respectively), indicating that these cultivars have larger seeds than the ones allocated in G1.

Based on the results provided by PCA and boxplot of the physical properties, we infer that the soybean cultivars comprising the G2 are more similar to each other for all properties assessed, except for USM, which in turn is the property for which the cultivars allocated to the G1 group are most similar. This similarity between soybean cultivars suggests a higher homogeneity in seed lots regarding these physical properties. In this sense, the cultivars allocated in G2 show to be homogeneous for volume, length, width, thickness, circularity, sphericity, equivalent diameter, projected area, surface area, surface-to-volume ratio (*SVR*), friction coefficient, unit mass, apparent specific mass, rest angle, and porosity of seeds, while G1 has a greater heterogeneity for these same properties.

Discussion

Defining the characteristics of seed similarities enables the adjustments of the equipment according to the seed lots received at the processing unit. Establishing quality control parameters in this manner is highly beneficial to the process. The homogenization of batches handled in the stages of receiving, pre-cleaning, drying, processing, and storage minimizes the negative effects of operations on quality and allows the storekeeper to seize greater control of the variables in the operations, including flow and flow rate, seed mass, velocity, temperature, and air pressure passing through the seed mass, as well as the dimensions, capacities and technologies of the equipment[6,8-10].

The identification of cultivars with homogenous physical seed properties contributes to increased efficiency in sizing, regulation, and checking of post-harvest equipment[11,12]. The clustering of cultivars according to the physical seed characteristics allows sizing and regulating the reception, transport, pre-cleaning, drying, processing, aeration and storage systems of post-harvest units in terms of capacities, inclinations, and dimensions of the equipment, flow, air temperatures for drying, and aeration/cooling of seed mass during storage. Homogenizing seed lots according to the properties of the cultivars improves the efficiency of the drying systems and the quality of the seeds, reducing the water content to levels that allow the conservation of their qualities in storage[13-15].

Furthermore, the knowledge of the physical properties of the lots of different cultivars favors the regulation of ventilation and cooling equipment to reduce the temperature of the seed mass in storage, minimizing changes in humidity, reducing the respiratory processes of the seeds and hence the consumption of the elements constituting the nutritive reserves of the seeds, in addition to changes linked to metabolic dynamics in the seeds during storage, affecting germination and vigour[7,15,16].

At batch receiving step, the seed flows in the discharge hoppers are gravity-based, with the inclination angle of the hopper's inner walls being higher than the rest angle of the seeds. Sphericity, diameter, projected area, surface area, the surface to volume ratio, coefficient of friction, volume variability, and specific seed mass all affect the static capacity of the hopper. In handling and moving the seed mass with bucket elevators, conveyor belts, and threads, the carrying capacity and mechanical damage to the seeds depends on the adjustments, including those made according to the physical properties of the seeds. Such adjustments are often related to apparent specific mass, sphericity, projected area, surface area, surface-to-volume ratio, coefficient of friction, and angle of repose of the seeds[12,14,15].

At pre-cleaning operation, technicians separate impurities and foreign matter from the seed mass using air handling machines and sieves of different holes that are adjusted according to the roundness, sphericity, equivalent diameter, and volume (length, width, and seed thickness) for a condition of seed mass flow and cleanliness[14,16]. The drying operation alters and affects the physical characteristics of the seeds. Seeds with high water content at harvest, usually in the range of 18 to 22%, are subjected to artificial drying to reduce seed moisture to approximately 12% (w.b.), making it more appropriate for storage[17]. However, reducing the water content of seeds requires heat and mass transfer processes, which can substantially change the quality and physical properties of seeds depending on the method and drying conditions[18].

Drying, in turn, causes changes in seed dimensions[19]. Volumetric contraction is the main phenomenon of seed alteration resulting from drying, which also alters circularity, sphericity, equivalent diameter, volume, and specific mass of seeds. These changes are resulting from reduction of the tension inside the cells due to the removal of water. Volumetric changes are the primary stimulus causing changes in the physical properties of seeds; importantly, these characteristics determine the size and shape of the sieve holes used in the processing of agricultural products after harvest[2].

At the soybean seed processing step, the goal is to classify lots by size to improve quality and establish a seed standard[5,18,20]. The beneficiation is a fundamental operation in the seed production program and improves seed quality by providing conditions for use and meeting the minimum marketing standards pre-established by legal norms[20,21]. In processing, the seeds go through several stages, though not all lots follow the same sequence. This means that operations in this process are performed depending on the species, cultivar, and physical characteristics of the seeds[21,22]. The equipment is sized and chosen for the processing capacity for each type of seed based on the physical characterization of the seed. The flow during the beneficiation process is long and commonly results in mechanical injuries caused by physical agents during their handling; besides causing direct damage, this opens the seeds to contamination by highly deleterious pathogens[23,24]. It is essential to characterize the seed lots according to the cultivar and its physical properties, highlighting the circularity, sphericity, volume, and specific mass.

The quality of the seed is directly associated with the removal of inert material, seed of weeds and other crops as well as mechanical mixtures with seed of other cultivars, which depends on the appropriate combination of cleaning and separation equipment, the arrangement of the machines in the seed processing unit, and the physical seed properties standardization[9,17,25]. The densimetric table improves the physical quality of the soybean seed lot by increasing the specific mass and tends to standardize the one-thousand seed mass[6,11,19]. In a study carried out by Bakhtavar et al.[26], which aimed to evaluate the evolution of physical characteristics (degree of humidity, percentage of impurity, apparent specific mass, and one-thousand seed mass) of the seeds of several soybean cultivars along the processing line, the authors concluded that the processing reduces the incidence of impurities in a lot of soybean seeds, which is mainly performed by the cleaning machine and finalized by the densimetric table.

Atungulu et al.[27] and Trombete et al.[2] reported that even with all the available technology during the reception, pre-cleaning and processing steps, there are qualitative and quantitative losses originated during storage when the seed mass is constantly subjected to external factors, such as temperature and relative humidity; chemical factors, such as the presence of oxygen; and biological factors, such as the development of bacteria and fungi[13,23]. Therefore, minimizing such losses due to seed heterogeneity in the stages before the storage process is essential for increased efficiency and consequent profitability of the soybean seed production process[28-31].

The technological advance with the genetic breeding and the appearance of different soybean seed cultivars generated a high variability of soybean seed lots with different physical characteristics, making it necessary, for higher operational yield in the post-harvest units, reduction of losses and gains in quality, the development of flexible equipment in terms of regulations and controls, considering similar groups of cultivar for physical seed properties. However, the beneficiation and storage processes of soybean seeds in Brazil still do not take into account the heterogeneity of seeds due to differences between cultivars. Given the Brazilian reality of seed production, identify similar soybean cultivars for physical seed properties helps form batch groupings for post-harvest equipment adjustments.

The study is the first to perform a clustering of cultivars based on the main physical properties of soybean seeds and identify the cultivars with the highest uniformity for the properties assessed. Given our findings, it is possible to ensure greater machine efficiency in post-harvest operations by using cultivars with uniformity for physical attributes. In this sense, we recommend that the processing and storage of seeds from soybean cultivars take into account cultivars with similar properties, that is, those belonging to the same cluster.

Declarations

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Competing interests

The authors declare no competing interests.

Authors Contributions

Methodology, P.C.C. and J.A.V.O.

Formal analysis, P.C.C., J.A.V.O., L.P.R.T., P.E.T.

Investigation, P.C.C., J.A.V.O., D.M.R., R.S.M.

Field experiment conduction, P.C.C., J.A.V.O., D.M.R., R.S.M.

Statistical Analysis, P.C.C., J.A.V.O., L.P.R.T., P.E.T.

Writing-original draft preparation, P.C.C., J.A.V.O., L.P.R.T., P.E.T.

Writing-review and editing, P.C.C., J.A.V.O., L.P.R.T., P.E.T.

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Tables

Table 1. Equations for determination of physical properties of soybean seeds

Physical properties of soybean seeds	Equation
$V = \frac{\pi LWT}{6}$	(1)
$ASM = UM/V$	(2)
$UM = ASM/(P-1)$	(3)
$PA = 3.14AB$	(4)
$ED = (LWT)^{1/3}$	(5)
$SA = 3.14(ED)^2$	(6)
$SVR = \frac{SA}{V}$	(7)
$Sp = \frac{(\pi LWT)^{1/3}}{L}$	(8)
$FC = 5.31 - 4.88Sp$	(9)
$C_r = PA/CA$	(10)
$P = \left[1 - \left(\frac{ASM}{USM}\right)\right]$	(11)
$RA = arctg(hr^{-1})$	(12)

Volume (*V*, mm³), Length (*L*, mm), Width (*W*, mm), Thickness (*T*, mm), Circularity (*Cr*), Sphericity (*Sp*), Equivalent diameter (*ED*, mm), Projected area (*PA*, mm²), Surface area (*SA*, mm), Surface-to-volume ratio (*SVR*), Circumscribed area (CA, mm²), Friction coefficient (*FC*), Unit mass (*UM* kg m^{-3}), Unit specific mass (*USM*, kg m^{-3}), Apparent specific mass (*ASM*, kg m^{-3}), Rest angle (*RA*, º), and Porosity (*P*, %), *A* is major semi-axis (mm), *B* is minor semi-axis (mm), *h* is height, *r* is ratio.

Table 2. Evaluation of physical properties of different soybean seed cultivars

Cultivars	*L* (mm)	W (mm)	T (mm)	*V* (mm^3)	C_r	*Sp*	*ED* (mm)	*PA* (mm^2)	*SA* (mm^2)	*SVR*	*CA* (mm^2)	*UM* (g)	*USM* (kg m^{-3})	*ASM* (kg m^{-3})	*RA* (°
68H0 RSF IPRO	8.695 b	8.030 a	7.395 a	270.210 b	0.924 a	0.904 a	7.857 b	54.80 a	193.84 a	0.717 b	1.090 b	0.230 a	903.114 b	713.670 c	22 b
6968 RSF RR	8.080 b	7.615 b	6.730 b	216.708 c	0.942 a	0.904 a	7.305 b	48.30 b	167.57 b	0.773 b	1.168 b	0.186 b	904.848 b	711.923 c	22 b
7166 RSF	7.970 c	7.615 b	6.675 b	212.011 c	0.955 a	0.910 a	7.253 b	47.64 b	165.17 b	0.779 b	1.138 b	0.151 b	886.678 c	718.887 c	23 b
3980 RR	8.315 b	7.235 b	6.315 b	198.817 d	0.870 b	0.854 b	7.101 b	47.22 b	158.31 c	0.796 b	1.672 a	0.161 b	1028.440 a	705.823 c	24 a
6139 RR	8.275 b	7.310 b	6.730 b	213.049 c	0.883 b	0.878 b	7.264 b	47.48 b	165.70 b	0.778 b	1.902 a	0.194 b	813.679 c	705.140 c	26 a
ATRIA RR	8.575 b	7.690 b	6.455 b	222.759 c	0.897 b	0.860 b	7.372 b	51.76 a	170.65 b	0.766 b	1.592 a	0.184 b	928.940 b	712.793 c	23 b
GURIA RR	8.260 b	7.640 b	6.650 b	219.621 c	0.925 a	0.888 b	7.338 b	49.53 b	169.06 b	0.770 b	1.316 b	0.179 b	890.156 c	722.540 c	21 b
MAMBA RR	8.145 b	8.025 a	7.690 a	263.052 b	0.985 a	0.956 a	7.788 b	51.31 a	190.44 a	0.724 b	1.212 b	0.237 a	918.069 b	776.350 a	22 b
BRS 7380 RR	8.445 b	8.000 a	7.335 a	259.339 b	0.947 a	0.918 a	7.751 b	53.03 a	188.66 a	0.727 b	0.971 c	0.210 a	987.591 b	706.010 c	24 a
2728 IPRO	8.150 b	7.465 b	7.335 a	233.543 b	0.916 a	0.919 a	7.488 b	47.75 b	176.05 b	0.754 b	0.997 c	0.179 b	930.765 b	721.380 c	21 b
2687 RR	8.660 b	7.680 b	6.875 b	239.293 b	0.887 b	0.872 b	7.548 b	52.20 a	178.90 b	0.748 b	1.432 b	0.193 b	974.159 b	729.993 b	23 b
2737 RR	8.145 b	7.680 b	7.115 a	232.919 b	0.943 a	0.919 a	7.481 b	49.10 b	175.74 b	0.755 b	0.997 c	0.186 b	971.282 b	715.280 c	24 a
CZ26 B42 IPRO	7.950 c	7.900 a	7.075 a	232.541 b	0.994 a	0.941 a	7.477 b	49.30 b	175.56 b	0.755 b	0.793 c	0.194 b	987.771 b	715.720 c	21 b
FLECHA IPRO	9.300 a	8.180 a	7.900 a	314.515 a	0.880 b	0.888 b	8.261 a	59.71 a	214.27 a	0.681 c	1.202 b	0.251 a	962.074 b	783.030 a	25 a
GXM 7148 IPRO	7.645 c	7.485 b	7.175 a	214.867 c	0.979 a	0.953 a	7.285 b	44.92 b	166.63 b	0.776 b	0.661 c	0.193 b	979.720 b	706.867 c	23 b
GXM 8372 IPRO	7.955 c	7.600 b	6.930 b	219.263 c	0.955 a	0.922 a	7.334 b	47.46 b	168.87 b	0.770 b	0.973 c	0.178 b	973.910 b	727.723 b	22 b
8573 RR	7.925 c	7.675 b	7.080 a	225.366 c	0.968 a	0.934 a	7.400 b	47.74 b	171.96 b	0.763 b	0.838 c	0.206 a	901.020 b	732.057 b	21 b
74178 IPRO EXTRA	7.970 c	7.710 b	7.000 a	225.107 c	0.967 a	0.928 a	7.398 b	48.23 b	171.83 b	0.763 b	0.917 c	0.178 b	973.646 b	714.480 c	24 a
CERTA IPRO	7.775 c	7.305 b	6.505 b	193.351 d	0.940 a	0.905 a	7.036 b	44.58 b	155.42 c	0.804 a	1.179 b	0.158 b	1045.720 a	727.507 b	22 b
ULTRA IPRO	8.465 b	7.960 b	7.360 a	259.535 b	0.940 a	0.916 a	7.753 b	52.89 a	188.75 a	0.727 b	0.950 c	0.183 b	910.941 b	717.790 c	26 a
KWS RK 6813 RR2	8.465 b	7.135 b	6.300 b	199.131 d	0.843 b	0.839 b	7.104 b	47.41 b	158.47 c	0.796 b	1.753 a	0.144 b	890.097 c	705.947 c	28 a
KWS RK 6813 RR	7.805 c	7.005 b	6.300 b	180.260 d	0.898 a	0.881 b	6.875 c	42.91 b	148.39 c	0.823 a	1.456 b	0.210 a	1649.155 a	704.530 c	22 b
M7739 IPRO	8.390 b	7.005 b	7.090 a	218.069 c	0.835 b	0.873 b	7.320 b	46.13 b	168.27 b	0.772 b	1.434 b	0.207 a	1009.928 a	711.447 c	21 b
5947 IPRO	7.685 c	7.075 b	6.720 b	191.213 d	0.921 a	0.912 a	7.010 b	42.68 b	154.29 c	0.807 a	1.111 b	0.151 a	982.014 b	731.720 b	22 b
7337 RR	7.995 c	7.140 b	6.725 b	200.903 c	0.893 b	0.891 b	7.125 b	44.81 b	159.40 c	0.793 b	0.750 c	0.170 b	1117.630 a	714.587 c	23 b
M6410	7.940 c	7.520 b	6.835 b	213.577 c	0.947 a	0.916 a	7.270 b	46.87 b	165.97 b	0.777 b	0.650 c	0.178 b	1166.406 a	719.243 c	25 a

NS 7007 IPRO	8.995 b	7.850 b	7.105 a	262.551 b	0.873 b	0.865 b	7.783 b	55.42 a	190.20 a	0.724 b	0.850 c	0.149 b	936.468 b	722.137 c	23 b
NS 6823 RR	8.640 b	7.850 b	6.175 b	219.179 c	0.909 a	0.849 b	7.333 b	53.24 a	168.83 b	0.770 b	1.060 b	0.118 c	978.605 b	728.797 b	23 b
NS 7505 IPRO	8.155 b	7.850 b	7.280 a	243.895 b	0.963 a	0.931 a	7.596 b	50.25 a	181.17 a	0.743 b	0.872 c	0.201 a	949.898 b	714.023 c	21 b
DESAFIO	8.495 b	7.850 b	7.125 a	248.654 b	0.924 a	0.900 a	7.645 b	52.34 a	183.49 a	0.738 b	1.151 b	0.212 a	966.867 b	739.370 b	20 b
TMG 1180GX RR	7.050 c	6.845 c	6.305 b	159.230 d	0.971 a	0.936 a	6.599 c	37.88 c	136.73 d	0.859 a	0.915 c	0.115 c	1131.251 a	728.887 b	22 b
TMG 7062 IPRO	8.030 b	7.635 b	6.985 b	224.114 c	0.951 a	0.920 a	7.387 b	48.12 b	171.33 b	0.764 b	0.998 c	0.191 b	980.769 b	720.033 c	21 b
8473 RR	8.380 b	7.750 b	7.005 a	238.085 b	0.925 a	0.899 b	7.536 b	50.98 a	178.31 b	0.749 b	1.131 b	0.206 a	845.507 c	598.723 d	20 b
TMG 1264 RR	7.885 c	7.075 b	6.605 b	192.832 d	0.897 b	0.891 b	7.029 b	43.79 b	155.15 c	0.805 a	1.310 c	0.206 a	1302.751 a	732.057 b	22 b
98Y30	7.905 c	6.990 c	6.750 b	195.192 d	0.884 b	0.893 b	7.058 b	43.37 b	156.40 c	0.801 a	1.292 c	0.204 a	1216.030 a	719.327 c	23 b
98Y52	7.865 c	7.000 b	6.855 b	197.507 d	0.890 b	0.901 a	7.085 b	43.21 b	157.62 c	0.798 b	1.204 c	0.199 a	1158.139 a	717.563 c	22 b
96Y90	7.915 c	7.045 b	6.500 b	189.681 d	0.890 b	0.883 b	6.991 c	43.77 b	153.47 c	0.809 a	1.400 c	0.204 a	1312.412 a	721.437 c	23 b
8579 RSF	7.770 c	6.855 c	6.485 b	180.766 d	0.882 b	0.886 b	6.881 c	41.81 b	148.67 c	0.822 a	1.393 c	0.178 b	1277.212 a	718.473 c	22 b
2686 IPRO	7.550 c	6.680 c	6.580 b	173.671 d	0.885 b	0.899 b	6.791 c	39.59 c	144.79 c	0.834 a	1.264 c	0.197 b	1242.014 a	719.780 c	23 b
NS 7447	7.040 c	6.620 c	7.540 a	183.899 d	0.940 a	0.983 a	6.920 c	36.58 c	150.36 c	0.818 a	0.878 c	0.183 b	1237.346 a	715.293 c	20 b
Average	**8.116**	**7.464**	**6.890**	**219.457**	**0.920**	**0.903**	**7.321**	**47.657**	**168.622**	**0.773**	**1.147**	**0.186**	**1030.576**	**718.708**	**23**

Volume (*V*, mm³), Length (*L*, mm), Width (*W*, mm), Thickness (*T*, mm), Circularity (*Cr*), Sphericity (*Sp*), Equivalent diameter (*ED*, mm), Projected area (*PA*, mm²), Surface area (*SA*, mm), Surface-to-volume ratio (*SVR*), Circumscribed area (CA, mm²), Friction coefficient (*FC*), Unit mass (*UM* kg m^{-3}), Unit specific mass (*USM*, kg m^{-3}), Apparent specific mass (*ASM*, kg m^{-3}), Rest angle (*RA*, º), and Porosity (*P*, %),

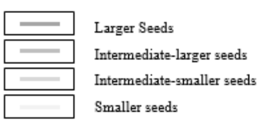

Table 3. Percentage of larger seeds (LS), intermediate-larger seeds (ILS), intermediate-smaller seeds (ISS), smaller seeds (SS) according to the results of Table 1

Physical properties	LS (%)	ILS (%)	ISS (%)	SS (%)
L	2.5	47.5	50	0.0
W	12.5	75.0	12.5	0.0
T	42.5	57.5	0.0	0.0
V	2.5	30.0	35.0	32.5
Cr	62.5	37.5	0.0	0.0
Sp	55.0	45.0	0.0	0.0
ED	2.5	82.5	15.0	0.0
PA	30.0	62.5	7.5	0.0
SA	20.0	45.0	32.5	2.5
SVR	25.0	72.5	2.5	0.0
CA	10.0	35.0	55.0	0.0
UM	37.5	57.5	5.0	0.0
USM	35.0	52.5	12.5	0.0
ASM	5.0	22.5	72.5	0.0
RA	22.5	77.5	0.0	0.0
P	35.0	65.0	0.0	0.0

Volume (*V*, mm^3), Length (*L*, mm), Width (*W*, mm), Thickness (*T*, mm), Circularity (*Cr*), Sphericity (*Sp*), Equivalent diameter (*ED*, mm), Projected area (*PA,* mm^2), Surface area (*SA*, mm), Surface-to-volume ratio (*SVR*), Circumscribed area (CA, mm^2), Friction coefficient (*FC*), Unit mass (*UM* kg m^{-3}), Unit specific mass (*USM*, kg m^{-3}), Apparent specific mass (*ASM*, kg m^{-3}), Rest angle (*RA*, º), and Porosity (*P*, %).