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Determination and sorting of cup plant seeds to optimize crop establishment

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By using cup plant (*Silphium perfoliatum* L.), which is native to North America, as biogas substrate, there is an economically interesting alternative or supplement to the predominantly used substrate maize. Due to its ecological advantages, it also contributes to the increase of biodiversity in the agricultural landscape. In order to establish an efficient crop stand with a long useful life of more than 10 years, a precise distribution of the seeds is necessary. The seeds are characterized by a strong heterogeneity in size and shape within a seed batch which negatively affects the quality of singling. The aim of the experiments was to quantify the size and geometry of seeds from different batches. In this context, seeds were measured and divided into fractions by using a self generated scheme and procedural analyses. In addition to optimize the singling by increasing the homogeneity, the study supports also the potential for improving the quality of commercially available seeds.

Keywords
Seed geometry, seed measurement, homogenization, precision sowing, precision seeding

The applicability of Silphium perfoliatum (*Silphium perfoliatum* L., below called cup plant) as renewable biomass and biogas substrate has been described in recent years in several research studies. The perennial composite can be harvested once a year and reaches yields up to 200 dt DM ha^{-1} (Biertümpfel and Conrad 2013, Hartmann et al. 2014). The wild plant stock from North America, with a so far marginal processed breeding (Blüthner et al. 2016), proved to be a promising alternative or supplement to maize (Biertümpfel et al. 2013). However, the occasionally difficult establishment of cup plant results in a limited practicability. Successful crop establishment has been achieved only by planting. This time and cost intensive method can be replaced by a sowing technique. By minor modifications on a pneumatic precision seeder sowing of cup plant is possible (Schäfer et al. 2015). Due to the slow development of young plants, the seeds have to be distributed precisely and equally to reduce weed pressure. A complete plant stock is the basic requirement for a successful cultivation of cup plant (Biertümpfel and Conrad 2013).

To achieve a final plant stock of four plants per m^2, a sowing rate of 15 to 18 seeds per m^2 is recommended (Biertümpfel 2011). Due to the high seed costs of 600 Euro kg^{-1} (accord about 1.700 € ha^{-1}), a reduction of the sowing rate improves the economic viability of the entire cultivation method. In order to avoid uneven plant stock, a high precision of the singling system is required. However, this is hindered by the highly heterogeneous seeds in terms of size and geometric shape and the low thousand grain weight of 16 to 20 g. In general, the seeds are shaped elliptically and a symmetrically to the longitudinal axis (Gansberger et al. 2015; Schäfer et al. 2017). As the thickness of about 1.5 mm is low compared to the length (about 9 mm) and width (about 4.5 mm), a precise singling and accurate adjustment of a precision seeder is complicated (Schäfer et al. 2017, Stieger and Brinkmann 1975).

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Problem and task

Different sizes and geometric shapes of the seeds have a negative effect on the quality of singling. Multiple seed batches have to be acquired in order to determine the seed size and geometry and to compare the results with Schäfer et al. (2017). In this study, four seed batches of different harvest years were assessed. The results indicate variations within and between the particular commercially available batches and harvest years. Furthermore, fractions for the homogenization of the seeds are to be defined. The influence on the singling quality is examined by Bonn's seeding test bench (Figure 1, Heier 2001, Schmittmann 2014). The study particularly aims to reduce the seed rate by a more precise singling.

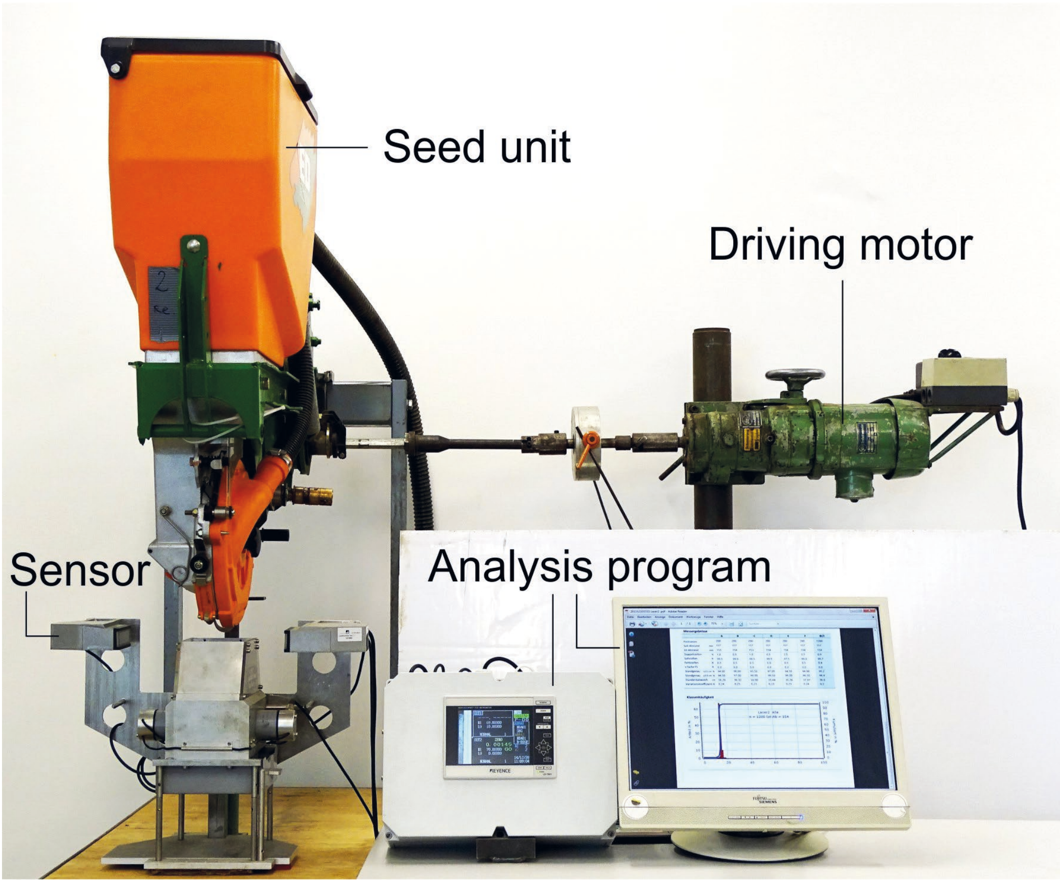


Figure 1: Bonn's seeding test bench (© A. Schäfer)

Material and methods

Four seed batches from 2006, 2007, 2011 and 2016 (n > 450) were available for the assessment. From harvest year 2011 two samples were provided, whereas from sample 2011b (n = 950) three fractions were formed on the basis of morphological features for procedural research. The seed was provided by N.L. Chrestensen Erfurter Samen- und Pflanzenzucht GmbH. The seeds were recorded by a flat bed scanner (Type Lide 220, Canon, Krefeld, Germany). In each scan, 50 seeds were determined and numbered with a resolution of 600 dpi. By a dial extensometer with digital display, the seed thickness was determined. The analysis of the digital scans of the seeds was carried out in the software nVision Designer (Version 2017.1, Impuls Imaging GmbH, Türkheim, Germany). To describe the seed size, the seed length, width, circumference and area were used. The length of the seeds represents the longest distance within the seed. Perpendicular to the length, the longest distance is defined as width of the seeds (Figure 2). To determine the seed geometry, the apex angle was identified. For this purpose, a straight line with maximum contact was applied to the tapered sides. The apex angle of the seeds was determined by the intersection point of both straight lines (Figure 2).

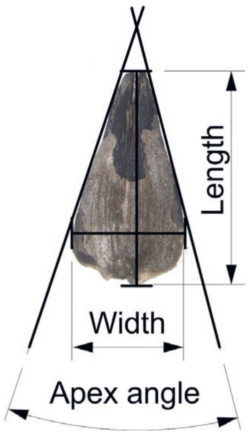


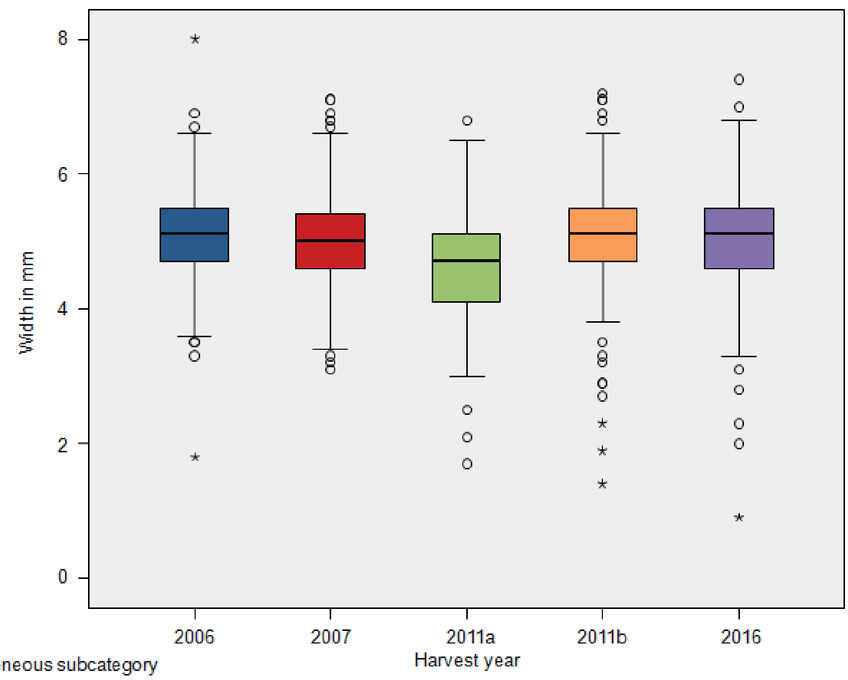
Figure 2: Exemplary demonstration of the parameters length, width and apex angle of an examined seed to describe the seed geometry

Based on the results, the seeds from sample 2011b were sorted manually in three angle fractions. The analysis of the singling was performed with a pneumatic precision seeder (Amazone ED 302) by Bonn's seeding test bench for each fraction. The germination ability was determined according to the ISTA standard 2012 and the germination power was tested under controlled conditions. Excel 2015 (Microsoft Corporation, Redmond, USA) was used for data preparation and descriptive statistics. The statistics program SPSS Statistics (Version 18, IBM Corporation, Armonk, USA) was used for complex data analysis. Whether a factor is normally distributed was tested by the Kolmogoroff-Smirnoff test (K-S test). A one-factorial variance analysis (significance level 0.05) was executed to investigate significant differences between several variants. With the Tukey test an additional multiple comparison of averages was performed. The means of the variants are listed below the boxplots.

Results and discussion

Seed size

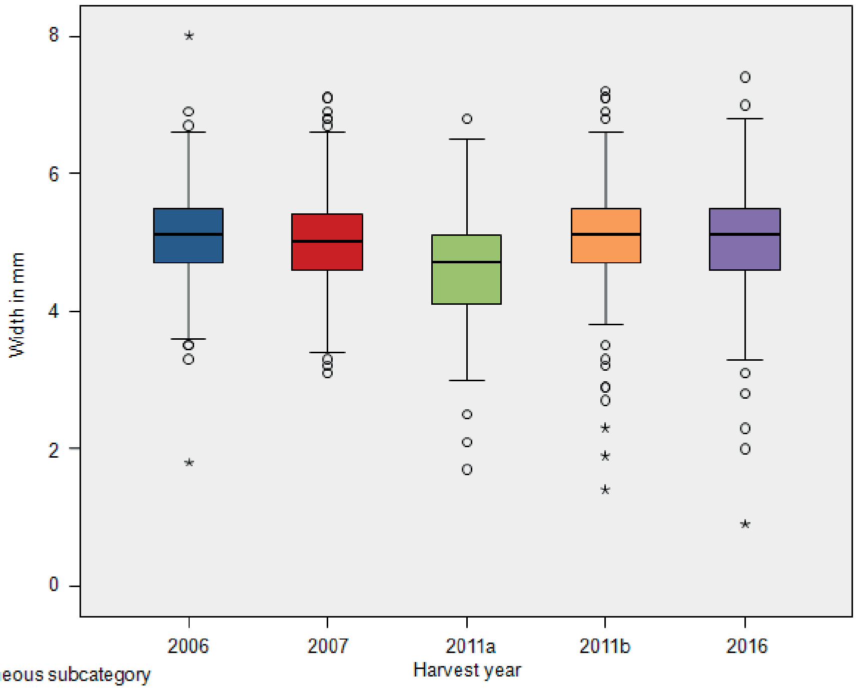
For precise description of the seed size, the determination of the seed length is required. Figure 3 outlines the statistically evaluated lengths of the seeds for the different harvest years. There are significant differences between the harvest years. The length of the seeds of 2011a has a minor average of 9.17 mm and differs significantly from the harvest years 2007 and 2011b with higher average values of 9.59 and 9.64 mm, respectively. In the harvest years 2006 and 2016, the significantly longest seeds emerged.



Homogeneous subcategory	2006	2007	2011a	2011b	2016
A			4,62		
B		5,02		5,12	5,03
C	5,13			5,12	5,03

Figure 3: Spread- and layer dimensions of the seed length in different crop years in mm

The compiled seed lengths correlate only partially with values described in the literature. Niqueux (1981) describes the seeds of cup plant with lengths of 9 to 15 mm and widths of 6 to 9 mm. These differences can be explained by the mechanical separation of the paleas of the seeds which is standard to increase the flowability in the seed meter. In case of a mechanical separation of the paleas carried out by the seed company as standard, deposit may remain on the tapered sides of the seeds. Compared to the results of Schäfer et al. (2017) with an average length of 8.39 mm, the seeds in this study are longer. The described heterogeneity of the seeds within a seed batch can also be confirmed (Schäfer et al. 2017). In addition to the seed length, the width is an important parameter for describing the seed size as well. Figure 4 shows the determined widths of the seeds for the different harvest years.



Homogeneous subcategory	2006	2007	2011a	2011b	2016
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Figure 4: Spread- and layer dimensions of the seed width in different crop years in mm

Significant differences in seed width occur between the harvest years. The seeds of crop 2011a have the significantly lowest seed widths. Thus, the seeds of this batch are shorter and narrower than the seeds of the harvest years 2006, 2007, 2016 and the batch 2011b. Noticeable is the high number of outliers caused by the mechanical separation of the paleas.

In conclusion, significant different dimensions of the seeds, especially within one harvest year (2011), can be explained by the following causes: The climatic conditions during seed ripening effects seed development. In climatically adverse years, it is particularly important for the plant to produce enough seeds. Nutrient and water availability also play a role (Assefa et al. 2015). Since the seeds originate from slightly breeded plants composed of different geographical origins, this influence on the seed size has to be checked (Assefa et al. 2015). The long flowering period and the uneven seed ripening are further potential reasons for the appearance of heterogeneous seeds (Gansberger 2016).

Seed gemoetry

We defined the apex angle as main parameter for seed geometry. All frequencies were plotted against the corresponding apex angles in a diagram highlighting three peaks. These peaks were taken to sort manually three fractions with the following apex angles: fraction 1 with 0–30°, fraction 2 with 30–45° and fraction 3 with 45–60°. The largest fraction represents fraction 2 with a percentage of 60%. Fraction 1 and 3 with about 20%, respectively, are significantly lower. These percentages are nearly identical across all tested samples. Figure 5 exemplarily shows seeds of the respective angle fractions.

With an apex angle of 27° seed A is elongate and narrow and can be assigned to fraction 1. Seed B has an apex angle of 38° and is characterized by a conical geometry (fraction 2). With an apex angle of 49° seed C is compressed and belongs to fraction 3 (Figure 5).

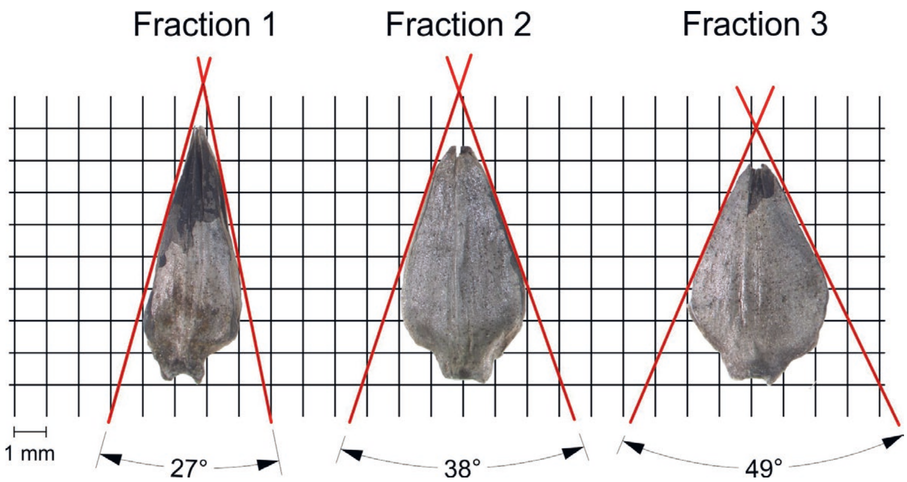

Figure 5: Exemplary representation of the seeds of the angle fractions 1 to 3.

Singling

The influence of the angle fraction on the quality of singling was investigated in a series of experiments with a pneumatic precision seed drill on the seeding test bench. In addition to varying the hole diameter from 0.8 to 1.8 mm, the velocities of 2.5 and 5 km h^{-1} were tested in combination with various vacuums. In addition to the angular fractions, the original sample was used in the experiments. Table 1 shows the results of the promising singling adjustments. The results confirm the recommended use of the single disc with a hole diameter of 1.2 mm (Köhler and Biertümpfel 2016, Schäfer et al. 2016).

Table 1: Relative distribution of the calibration test using a singling disc with hole diameter of 1.2 mm, speed 2.5 km h^{-1} and negative pressure 67.6 mbar for the three fractions and the original sample

Sample	Fraction 1 0–30°	Fraction 2 30–45°	Fraction 3 45–60°	Original sample
Doubles in %	10,3[a]	10,2[a]	13,9[a]	11,0[a]
Target in %	88,4[b]	88,3[b]	82,3[a]	86,3[ab]
Single misses in %	1,3[a]	1,3[a]	2,8[a]	2,7[a]
Multiple misses in %	0,0[a]	0,2[a]	1,0[a]	0,0[a]

The amount of the target spacings is a quality characteristic in the evaluation of precision sowing. Although the use of fractions 1 and 2 does not achieve any target spacings as e. g. with sowing sugar beet, nevertheless an increase of target spacings compared with the original sample can still be achieved. At the same time, the percentage of misses is halved at 1.3% (Table 1). Thus, an increase of singling quality can be documented. Due to the agronomic characteristics, sowing of these fractions is also beneficial. As cup plant is not competitive towards weeds, misses can lead to sustainable problems and should be avoided. By contrast, doubles are compensated by increased growth of the neighboring plants.

Agronomic parameters

The relative germination ability, the relative germination power in relation to all investigated variants and the thousand grain weight were determined for the examination of agronomic parameters (Table 2). Although fraction 1 has a relative germination ability of 112%, this fraction records with 82% only a substandard germination power. In addition, the seeds of this fraction have the lowest thousand grain weight. The most favorable ratio of germination ability and germination power for all investigated samples achieve angle fractions 2 and 3. Basically, there is a relationship between thousand grain weight and the germination power.

Table 2: Relative germination ability and relative germination power for three different angle fractions and the original sample and their thousand grain weight

Sample	Fraction 1 0–30°	Fraction 2 30–45°	Fraction 3 45–60°	Original sample
Relative germination ability in %	112	97	96	97
Relative germination power in %	82	107	108	104
Thousand grain weight in g	15,6	18,5	17,4	17,4

From the parameters listed in Table 2, the germination power is the most important in establishment process. Especially seeds with a low germination power, including cup plant, should be sown as flat as possible to secure the field emergence. Flat deposition of seed, however, increases the risk of dehydration of seedlings which can lead to total failure. Particular in the recommended sowing period of cup plant from end of April to end of May, there is an increased cultivation risk. By using seeds with a high germination power these risks can be limited. A deeper deposition of the seeds would achieve a better water supply from the capillary uplift. Even in the case of crust of the soil surface, a higher germination power of the seeds or seedlings is advantageous. Thus, due to the superior germination power by using the fractions 2 and 3, procedural advantages can arise in crop establishment. By the proposed fractionation an increase in quality can be expected.

Relevance for cultivation

In order to evaluate the results for crop establishment, the combination of all investigated parameters has to be considered. Although fraction 2 achieved the most accurate singling as well as the highest increase in seed quality, exclusive marketing of this fraction would result in a waste of 40%. Without consideration the costs of fractionation this will lead to an equal increase of seed costs. By using fraction 1 an identical singling quality could be achieved. On the other hand fraction 3, convinces by a superior germination power compared to fraction 1 and the original sample. To exploit the procedural advantages of a fractionation as well as to avoid an increasing of seed costs, a selective marketing of individual batches or a combination would be possible. Since the benefits of a higher germination power for the total establishment process overweigh, a combination of fraction 2 and 3 should be considered to secure field emergence. From the combination of these positive characteristics, it would be possible to reduce the sowing rate from the previously recommended 15 to 18 to 12 seeds per m^2. By reducing the sowing rate by 3 to 6 seeds per m^2, with a thousand grain weight of 18 g and a seed price of 600 € kg^{-1} 300 € to 600 € ha^{-1} can be saved without fractionation costs. Thus, the attractiveness of cup plant for farmers is significantly increased.

Conclusions

The research gives evidence to major variations of the measured parameters in as well as between the seed batches. The apex angle of the seeds provides a description of the different seed shapes within a seed batch. In addition, this parameter allows a fractionation to increase homogeneity. By sorting and preparation of fraction 2, it was possible to achieve a more precise singling and an increased seed quality. However, in the case of wasting the other fractions (40%), this advantage is offset by a higher seed price. Due to the small differences in assignment of the seeds, crop establishment is optimized by the increase of seed quality. Therefore, we propose the combination of fractions 2 and 3. This allows a reduction of seed costs by 300 to 600 € ha^{-1}. Thus, this investigations contribute to the procedural optimization of the cultivation of cup plant.

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