Studying and Developing Fraction Technologies for Seed Separation Using Pneumatic Table Separators

V M Drincha¹, Y Z Dondokov¹

¹Federal State Budgetary Educational Institution of Higher Education "Arctic State Agrotechnological University"; 677007, Russia, Yakutsk, Sergelyakhskoe highway 3 km, building 3; Tel. 89168369027

E-mail: vdrincha@list.ru

Abstract. This article considers the development of fraction seed separation technologies using pneumatic table separators (PTS). The authors studied the physical and mechanical properties of wheat seeds including their density, dimensions, individual seed weight, friction coefficients, suspension velocity, and the form factor. The authors found some correlations for seed separation parameters using PTS. It was established that PTS separate seeds based on a set of properties, the most important of which is the seed density. The authors established that the efficient separation of difficult-to-separate seed mixes on a PTS requires separating the material before feeding it into the PTS into two equal factions based on the seed length and using the trieur cylinder. Each of the fractions should be processed independently. By creating seed mixes with more homogeneous seed lengths, it is possible to improve the separation efficiency for the mixes that are difficult to separate by 8-15% on average.

1. Introduction

To obtain high and stable yields of agricultural crops, it is necessary to have good seeds. The conditions under which the seeds develop impact their sowing properties and the resulting yields. The sowing, biological, and yield properties of seeds are higher if they are formed in the central flower or blossom, during the first formation period, and if they are formed on the main stem [7, 11]. Sowing these seeds results in 15-57% yield gains. However, it is currently impossible to select seeds that would have high yields. Therefore, seeds are normally selected using indirect methods: by assorting the seeds according to their physical and mechanical properties using complex separators [15, 16].

The physical and mechanical properties of seeds include their dimensions, volume, shape, individual weight, density, elasticity, hardness, undersize, surface type, etc. Among these properties, seed undersize, individual weight, and density have the highest practical significance. Individual seed weight reflects the content of nutrients in them and is used as a universal indicator of their development because heavy seeds are more productive than light-weight [14, 17]. Density is another important seed quality indicator that helps assess the productive properties of seeds. To improve the productivity of seeds, we can eject low-productivity seeds from the mix.

Natural conditions of plant development and ripening (e.g. droughts, early harvesting, etc.) may cause the formation of low-productivity undersize seeds. Seed separation is used to increase the pro-
portion of highly productive seeds in the mix by ejecting low-productivity seeds. In practice, low-productivity seeds are ejected based on their density and individual weight.

Density-based seed separation in water was used long before modern separation technologies appeared. The density-based separation of barley seeds in water allowed for the production of high-productivity seeds. The yield gains in these experiments are 18-20%, which is a good result [8, 13]. However, 30% of seeds are lost during these procedures, which is several times higher than the permissible level in the agricultural sector. Besides, after liquid-based separation, seeds need to dry, which significantly complicates the seed preparation technology and makes it more expensive.

Modern seed preparation technologies include density-based separation without liquids in a fluidized bed formed by the airflow and base surface vibration, i.e. the working elements of PTS [6, 10]. Despite the high potential of PTS separation, it is often used inefficiently. One of the key reasons for that is the negative influence of some of the physical and mechanical properties of seeds on the PTS separation process. [9, 18].

The experience of the authors and the analysis of Russian and foreign research works on the improvement of technical efficiency of gravity separators showed that the development of fraction technologies and the separate PTS treatment of each fraction is a key area of studies nowadays [3, 5, 19].

2. Relevance
Industrial seed production in developed countries uses PTS in strict accordance with the requirements for seed certification.

In Russia, PTS are used to process a small proportion of the country’s seed stock. Seed separation technologies using PTS have higher seed losses and forage wastes due to the impossibility of ejecting difficult-to-separate impurities. According to agrotechnical requirements, losses during PTS seed separation may amount to 10% of the material submitted for processing. In practice, up to 20% of the entire processed seed volume goes to forage wastes [1, 2, 12].

3. Statement of problem
The development of fraction separation technologies for cereals is based on the separating factors of seeds and the separation properties of seeds in separator devices. The separation properties used by the majority of separators are implicit, which makes it impossible to determine the best fractioning technologies for seed separation. Separators that process seeds using sets of parameters, like PTS, are the biggest problem.

After the separation parameter is determined, it can be analyzed to determine the possible fractioning options for the seeds before they can be fed into the separator by reducing the significance of the factors (specific physical and mechanical properties) that have a negative impact on the main separation parameters.

The goal of this research is to develop fraction seed separation technology, including the use of PTS, by considering the set of separation parameters used.

4. Theory
To determine the set of seed separation parameters for PTS, we used the mathematical pattern recognition [4] to study the physical and mathematical properties of seeds, such as the key dimensions (thickness, width, length), individual weight, density, volume, critical suspension velocity, kinetic friction coefficient, and seed volume and shape coefficient determined using the following formula:

\[
z = \frac{\pi}{6} \left( \frac{d_g}{d_e} \right)^3
\]

where \(d_g\) is the geometric seed diameter in mm; \(d_e\) is the diameter of the equivalent sphere in mm. The mathematical pattern recognition method was used to determine the set of physical parameters of seeds during separation in a fluidized bed on the PTS deck.
Seed dimensions were determined along three perpendicular axes using a micrometer. The individual seed weight accurate to 0.01 g was determined using digital scales. The critical seed suspension velocity was determined using a pneumatic classifier RPK-30. Friction coefficients were determined using a specialized device. Seed density was determined by their subsequent immersion in solutions of different acids.

Due to the labor intensity of seed parameter measurement, the analytical correlations with the separation parameters were only determined for wheat seeds:

\[ y = -0.791\rho - 0.099a - 0.067b - 0.033c + 0.014\varphi - 0.005v + 0.599z \]  

(2)

where \( \rho \) is the seed density, g/cm\(^3\); \( a, b, \) and \( c \) are the seed length, width, and thickness respectively, mm; \( \varphi \) is the kinematic friction coefficient; \( v \) is the critical suspension velocity; \( z \) is the seed shape coefficient.

The analysis of equation (2) shows that the most important properties of the seeds fed into the PTS are their density and the shape coefficient calculated using equation (1). The least significant seed properties include the critical suspension velocity and thickness.

Due to its physical properties, seed separation in a fluidized bed is based on the density of seeds, while other parameters have little differences [20, 21].

Thus, if seed mix components have greater differences in density than in other parameters, we can reduce the significance of other properties and equalize other parameters in the seeds to improve the efficiency of PTS separation in a fluidized bed.

The third important seed property impacting the efficiency of PTS separation is the seed length. To separate seeds by their length, seed production facilities use the trieur. Based on expression (2), we determined that the separation of seeds by their length helps make the grain size distribution of the seed mix more homogeneous and thus improve the significance of density, as well as the efficiency of PTS separation. This assumption was checked and confirmed in the experience where wheat seeds were separated in two equal fractions using a trieur with the mesh size of 6.5 mm before the seeds were fed into the PTS. Each fraction obtained in the trieur was processed in the PTS independently. We established that this fraction processing helps increase the efficiency by 8-14% on average.

After we obtained the results of length fractioning, we tested the possibility of ejecting difficult-to-separate seeds of mountain bluet (Centaurea montana) from the lucern seeds before they were fed into the PTS. The experiments conducted helped obtain a new fraction separation technology for lucern seeds (Figure 1).

Figure 1. Fraction purification technology for lucern seeds with the separation of seeds into two fractions: 1 – light impurities; 2 – large impurities; 3 – long impurities; 4 – small (short) fraction of the main seeds; 5 – large (long) fraction of the main seeds (fractions 4 and 5 are processed in the PTS).
We used the developed fraction technology to separate the seeds into two fractions, after which each of the fractions (4 and 5) were processed in the PTS independently. This fractioning technology was tested in a laboratory of the All-Russian Research and Development Institution for Agricultural Mechanization and it was used in the farms of the Republic of Uzbekistan.

The suggested fraction technology helps increase the efficiency of the bluet and lucern seed separation by 13-15% on average.

Since currently there are no separators that separate seeds by their shape determined using (1) and (2), it is impossible to separate seeds into fractions.

The individual weight of seeds in expression (2) has almost no impact on the PTS separation parameter. In practice, seeds from separated fractions have different individual weights during the PTS separation [4, 17].

This difference between the obtained separation parameter and the practice can be explained by the fact that the individual weight of seeds has a high correlation rate with seed density, and the density of seeds during PTS separation is a more significant parameter.

To explain this difference, we conducted a large experiment using the seeds of oats, rye, and field pea. The seeds were fed into the PTS, and we determined the weight of 1000 seeds in the fractions produced by the PTS (Figure 2).

![Figure 2](image_url)

**Figure 2.** The correlation between the weight of 1000 seeds and their output:
1 – oats; 2 – rye; 3 – field pea.

After the PTS separation of wheat, barley, and oat seeds, the weight of 1000 heavy fraction seeds increases on average by 10%, and the homogeneity of medium and heavy fractions increases by 7-12% compared to the initial mix.

We used statistical processing methods to produce reliable models describing the changes in the weight of 1000 seeds depending on their output in the PTS (Table 1).
Table 1. The correlation between the weight of 1000 seeds (and their output) for the seeds along the discharge edge of the deck.

| Model        | Model constants | RMS deviation | Corr. coeff. |
|--------------|-----------------|---------------|--------------|
| **Rye**      | a \(+\) b \(\times\) q | 33.33 | 0.078 | 0.80 | 0.97 |
| **Field pea**| a \(\times\) \(\exp((-\(b-x\))^{2}/(2\times c^{2}))\) | 209.6 | 49.28 | 164.0 | - | 1.33 | 0.96 |
| **Oats**     | a/(1+\(\exp(b-cx)^{(\times\text{-d})}\)) | 45.52 | -2.69 | -0.026 | 4.55 | 0.12 | 0.99 |

Thus, the experiments conducted confirm that the separation of seeds in the PTS occurs based on the weight of 1000 seeds. However, this property cannot be used to develop fraction-based separation techniques because the existing separators do not separate seeds based on the weight of 1000 seeds, and this parameter correlates with other seed properties in most cases.

5. Applicability
The developed fraction separation technologies using the PTS can be used in cereal seed production during the preparation of cereal seeds and small seed crops.

The obtained correlations between the weight of 1000 seeds and their output can be used for the selection of the PTS parameters to provide the required seed separation quality.

6. Conclusions
1. The improvement of seed quality during the pre-sowing treatment by PTS separation is extremely important for seed production. The development of fraction separation technologies is one of the most promising solutions for that.

2. The production of seeds with improved sowing qualities is one of the key goals of seed separation in PTS. This process also aims to eject the impurities, that have different densities and cannot be separated using other methods, from the main crop. These impurities include the seeds infected with skiting smut, ergot cloves, peas infested with bruchus, germinated and unripe seeds, bare seeds, wild oat, horse sorrel, white charlocks, etc.

3. The efficient separation of difficult-to-separate seed mixes on a PTS requires separating the material before feeding it into the PTS into two equal factions using the trieur cylinder. Each of the fractions should be processed independently. The homogenization of the grain size distribution in seed mixes helps improve the separation efficiency for the mixes that are difficult to separate by 8-15% on average.

4. During the research, we established that PTS separate seeds based on a set of physical and mechanical properties: seed density, dimensions, and shape. The PTS separation also takes into account the weight of 1000 seeds, which is confirmed in separation experiments with a wide range of rye, field pea, and oat seeds.

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