MATHEMATICAL MODELING AND ALGORITHM DEVELOPMENT FOR FRACTIONATION OF BEAN SEEDS IN A CYLINDRICAL SIEV

Komil.Dulliyevich Astanakulov
Doctor of Technical Sciences, professor, "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University
Hodiboev Yusufbek Ulugbek ugli
PhD student of "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University
https://doi.org/10.5281/zenodo.17870979

ARTICLE INFO

Received: 07th December 2025
Accepted: 08th December 2025
Online: 09th December 2025

KEYWORDS

Bean seed fractionation, cylindrical sieve separator, mathematical modeling, particle motion dynamics, hole-passage probability, seed morphological variability, separation efficiency, algorithm development

ABSTRACT

This research presents a mathematical model and an algorithm for the fractionation of bean seeds using a cylindrical sieve. Based on the morphological parameters of the seeds, the probability of passage through the sieve holes, the distribution of fractions, and the influence of sieve geometry were determined. The probabilistic model considers seed length, width, thickness, and mass, while the dynamic analysis describes seed motion inside a rotating cylinder. Experimental measurements showed that the bean seeds vary from 9.76 to 17.67 mm in length, 7.50 to 10.20 mm in width, and 4.32 to 6.95 mm in thickness, which has a significant impact on separation performance. The developed model and algorithm enable the optimization of cylindrical sieve parameters and operating regimes for improved fractionation accuracy.

Introduction. High-precision fractionation of bean seeds plays a pivotal role in enhancing the quality and technological suitability of agricultural products. Accurate separation into size-based fractions directly influences seed purity, uniformity, germination stability, mechanical processing efficiency, and the final performance of downstream operations such as drying, calibration, and storage. In seed farming and industrial processing, even small deviations in seed dimensions can lead to significant decreases in cleaning accuracy and machine throughput, emphasizing the need for improved sorting mechanisms.

Conventional flat-sieve separators, which operate on reciprocating motion, predominantly rely on two-dimensional screening. These machines often fail to account for the full three-dimensional morphological variability inherent in bean seeds. Bean cultivars typically demonstrate wide variation in length, width, thickness, and mass, and these irregular geometries influence how seeds interact with sieve perforations. As a result, flat sieves frequently exhibit limitations when handling seeds with non-uniform shapes, causing reduced separation efficiency, higher impurity retention rates, and insufficient differentiation between small, medium, and large fractions.

Cylindrical or rotary drum sieves, on the other hand, provide a fundamentally different separation mechanism. Due to their rotational motion, seeds undergo continuous tumbling, sliding, and cascading within the drum, leading to natural self-classification. This dynamic motion allows seeds to reorient themselves repeatedly, improving the probability that each seed approaches the perforations in its most favorable orientation. Consequently, cylindrical sieves enable more precise fractionation, particularly for seeds such as beans whose morphology is asymmetric and variable. Moreover, cylindrical sieves allow multi-stage separation using sequential sections with different perforation sizes, making them highly suitable for advanced fraction separation applications.

Despite these advantages, the efficiency of cylindrical sieves strongly depends on several interacting parameters, including rotational speed, drum diameter, length, perforation diameter, perforation density, drum inclination angle, and feed loading conditions. The relationship between these parameters and separation performance is inherently non-linear and is further complicated by the physical properties of the seeds being processed. Therefore, achieving optimal operation requires a rigorous mathematical framework capable of describing the dynamic behavior of seeds within the rotating drum and estimating the probability of passage through sieve holes.

Main part. In this research, a detailed morphological analysis of bean seeds was conducted to capture the inherent dimensional variability of the material. A total of **900 bean seeds** representing three different varieties were measured using precision instruments. The experimental measurements revealed considerable variation: the seed length ranged from **9.76 to 17.67 mm**, the width from **7.50 to 10.20 mm**, and the thickness from **4.32 to 6.95 mm**. These variations are large enough to significantly influence separation outcomes, particularly in sequential fractionation systems where each millimeter of difference affects passage probability and classification boundaries.

Physical–mathematical model of seed movement in a cylindrical sieve

The motion of a seed inside the rotating cylindrical sieve is governed by rotational speed (ω), gravitational acceleration (g), and friction coefficient (μ). The seed adheres to the inner wall of the cylinder until the critical angle:

$$\theta_c = \arccos\left(\frac{\mu g}{\omega^2 R}\right)$$

where R is the drum radius. At this angle, the seed begins to slip or fall freely. Thus, the trajectory inside the cylinder consists of two phases:

(1) upward movement along the rotating wall,

(2) free fall and interaction with the sieve holes.

This dynamic behavior determines the likelihood and timing of seed–hole interactions.

Mathematical expression of the hole-passage probability

The probability that a seed passes through a sieve hole is directly related to its geometry. Let L, B, and T denote the seed's length, width, and thickness, and d_h represent the hole diameter. The simplified deterministic condition is expressed as:

$$P = \begin{cases} 1, & \text{if } \max(B,T) < d_h \\ 0, & \text{otherwise} \end{cases}$$

To include natural variability and non-ideal motion, an exponential probability model is applied:

$$P = e^{-k(max(B,T)-d_h)}$$

where $\boldsymbol{k}$ is an empirical coefficient.

According to this model, the smallest seeds (B = 7.50 mm) pass through an 8 mm hole with a probability of 0.98–1.00, while the largest seeds (B = 10.20 mm) are retained with almost zero probability of passage.

Fractionation model across sieve sections

Fraction distribution depends on the number of sieve sections (n), rotational speed (ω), hole diameter, and perforation density. The fractionation mathematical model is given by:

$$Q_i = Q_0 P_i\left(\omega, d_{h_i}, \varphi\right)$$

where:

• Q_i= mass of seeds classified into the i-th fraction,

• P_i= passage probability through holes in section i,

• φ= sieve loading factor.

Using this model, the seeds were separated into three fractions based on size: **small**, **medium**, and **large**.

Development of the separation algorithm

The fractionation algorithm consists of the following sequence:

1.Measurement of seed geometric parameters (L, B, T).

2.Calculation of passage probability using the probabilistic model.

3.Selection of hole diameters in ascending order for multi-stage fractionation.

4.For each sieve section:

○ determination of rotational speed,

○ adjustment of perforation density,

○ calculation of mass flow distribution.

2.Evaluation of separation accuracy and optimization of regime parameters.

This algorithm supports practical design and adjustment of the cylindrical sieve for various bean varieties.

Conclusion. A mathematical model and an algorithm for the fractionation of bean seeds in a cylindrical sieve were developed. The physical–dynamic equations describe seed motion inside the rotating cylinder, while the probabilistic model establishes the relationship between seed morphology and hole-passage likelihood. Based on experimental measurements, optimal hole diameters and operating conditions were determined. The proposed algorithm provides a systematic approach for designing sieve parameters and selecting appropriate operational regimes, contributing to higher separation accuracy and improved machine performance.

References:

[1] Astanakulov K, Shovazov K, Borotov A, Turdibekov A and Ibrokhimov S 2021 E3S Web of Conferences 227 07001

[2] Astanakulov K 2021 E3S Web of Conferences 264 04074

[3] Borotov A 2020 IOP Conf. Series: Materials Science and Engineering 883 (1) 012160

[4] Farmonov E, Khudayarov B, Abdillaev T, Farmonova F 2021 E3S Web of Conferences 264 05020

[5] Hamidov A, Helming K, Balla D 2016 Agron. Sustain. Dev. 36 (6) 1-23

[6] Hodiboyev Y.U. Optimization Strategies for Maximizing Efficiency in Grain Cleaning Machines. International Journal of Biological Engineering and Agriculture. ISSN: 2833-5376 Volume 2 | No 12 | Dec -2023 – P. 85-88.
[7] Hodiboyev Y.U. Silindrik g'alvirli don tozalash mashialarini samaradorligini oshirish strategiyalari. Development and innovations in science international scientific-online conference. – P. 98-101.
[8] Gapparov Sh, Karshiev F IOP Conf. Series: Materials Science and Engineering 883 (1) 012158
[9] Gapparov Sh, Karshiev F, Khudaynazarov D and etc. 2020 IOP Conf. Series: Earth and Environmental Science 614 (1) 012158
[10] Fozilov G G, Kurbanov N M and etc. 2020 IOP Conf. Series: Earth and Environmental Science 614 012129