DETERMINING EFFECT OF GROWING CONDITIONS ON HEMP SEED PROPERTIES

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Abstract. The object of the study comprises the technological processes of cleaning, fractionation, and pneumatic separation of industrial hemp seeds, as well as the physical characteristics of the seeds. The subject of the research is the variation of the physical characteristics of industrial hemp seeds depending on the cultivar, the soil and climatic growing conditions. Patterns of changes in seed dimensions were established for the cultivars "Hlesiia" and "Hlukhivskyi 51" (grown in the fields of the Institute of Bast Crops, Hlukhiv, Sumy region, Ukraine), the cultivar "Hlukhivskyi 51" (Chernihiv, Chernihiv region, Ukraine), and the cultivar "Hliana" (Lebedyn, Sumy region, Ukraine): width 2.10-4.73 mm, length 2.73-5.98 mm, and thickness 1.91-3.94 mm. The seeds were characterized by a complex geometric shape and a wide range of dimensional variability, even within a single cultivar. The highest bulk density, 537 $g \cdot L^{-1}$, was observed for sample 1 of the cultivar "Hlesiia" (sample 2, cultivar "Hlukhivskyi 51" - 448 $g \cdot L^{-1}$; sample 3, cultivar "Hlukhivskyi 51" – 510 $g \cdot L^{-1}$; sample 4, cultivar "Hliana" – 445 $g \cdot L^{-1}$). The mean sliding angle for the coarse fraction of the cultivar "Hlesiia" was 34.10, for the medium fraction – 30.40, and for the fine fraction - 33.30, respectively. The mean static coefficient of friction for the coarse, medium, and fine seed fractions was 1.48, 1.70, and 1.52, respectively. The medium fraction exhibited the highest coefficient of friction, indicating specific features of its surface structure. For the coarse fraction of the cultivar "Hlesiia", the minimum fluidization (pseudo-fluidization) velocity was 5.2 $m \cdot s^{-1}$, and the terminal velocity was 7.2 $m \cdot s^{-1}$, which were the highest among all fractions. The medium and fine fractions, having lower mass and smaller dimensions, showed terminal velocities of 6.8 and 5.8 $m \cdot s^{-1}$, respectively. The scientific novelty lies in the established patterns, which made it possible to determine rational air velocity values in pneumatic separation channels, as well as the critical inclination angles of chutes and hopper walls. This enabled a transition from a descriptive characterization of seed properties to a parametric selection of aspiration regimes and conditions for stable gravity flow.

Keywords: industrial hemp, cultivar, geometric dimensions, bulk density, sliding angle, coefficient of friction.

Introduction

The physical and mechanical characteristics of industrial hemp seeds at all stages of processing have a significant impact on the efficiency of technological operations [1-2]. Studies [3-6] emphasize the importance of investigating the mechanical and technological properties of seeds and their substantial influence on processing procedures, equipment adjustment to achieve optimal performance, and the quality of the final products. When handling seed material, physical and mechanical characteristics are essential for determining processing parameters and affect throughput, energy consumption, and wear of working components. The development of models and mathematical relationships, identification of optimal and rational parameters of working elements, and the determination of operating modes of equipment are impossible without a thorough understanding of the seed material properties [7-8]. Among the physical and mechanical characteristics of seeds, shape, size, specific weight, the external structure of the seed coat, the static coefficient of friction, and others are commonly distinguished [9-11]. At the same time, the influence of the variety and soil-climatic growing conditions on the geometric, physical, and physico-mechanical properties of industrial hemp seeds remains insufficiently studied, which complicates the substantiation of the parameters of their cleaning, fractionation, and pneumatic separation processes.

Materials and methods

Industrial hemp seeds were used for the experiments. The seed material differed in soil and climatic growing conditions, cultivar, and qualitative and quantitative indicators. Before the experiments, the seeds underwent standard preparation, which included cleaning, drying to a moisture content of 10.0%, sorting, and packing into 35 kg bags. Prior to testing, the seeds were stored in bags in a storage facility. When analyzing seed lots, the following parameters were determined: seed size, fractional composition of the lot, seed moisture content, 1000-seed weight, bulk density, sliding angle, and terminal velocity of seeds. Sampling was performed in accordance with the methodology specified in DSTU 4138-2002 "Seeds of agricultural crops. Methods for determining quality". Mathematical processing of the data was carried out using generally accepted methods. During the statistical processing of the experimental data, the arithmetic mean, standard deviation, standard error, 95% confidence interval, and the range of variation of the indicators were determined. The statistical significance of differences between the variants was assessed by analysis of variance (ANOVA) at a significance level of $p < 0.05$ using Statistica and Microsoft Excel software.

For each sample, five replicates weighing 1.0 kg each were prepared. The experiments were conducted under laboratory conditions at an air temperature of 21 °C and normal relative humidity.

The seed size was determined by three parameters (width, length, and thickness) using an electronic caliper with an accuracy of 0.01 mm. For each experimental variant, 100 measurements were performed. The obtained data were processed statistically according to generally accepted procedures. The fractional composition of seeds was determined by separating a lot sample by size (seed width) into three fractions. For this purpose, seeds were sieved using oblong-aperture sieves with openings of 3.0×20 mm and 2.5×20 mm. As a result of sieving, three seed fractions were obtained: coarse (≥ 3.0 mm), medium (2.5-3.0 mm), and fine (≤ 2.5 mm).

Then the mass of each of the three fractions was measured. Subsequently, the percentage content of each fraction in the seed lot was calculated.

The sliding angle, static coefficient of friction, and terminal velocity were determined for three fractions (large, medium, and small) of sample 1 of the Hlesiia variety.

Moisture content, 1000-seed weight, and impurity content were determined in accordance with DSTU 4138-2002. The moisture content of hemp seeds was determined by drying whole seeds at 130 °C for 60 min, and the weight of 1000 seeds was determined by the method of eight replicates of 100 seeds each without selection.

Bulk density was measured using a 1000 mL graduated cylinder. The seed sample was freely poured into the cylinder without tapping or compaction, filling it with excess. The excess seeds were removed by leveling the surface along the rim of the container with a ruler, after which the seed mass was recorded using electronic scales with an accuracy of 0.01 g. The number of replicates for each sample was 12.

The sliding angle of seeds was determined using a test stand consisting of a frame, an inclined plane (sliding board), and an adjustment mechanism (screw drive). The screw driver was used to adjust the inclination angle of the plane relative to the horizontally positioned frame. The sliding angle was measured on a painted steel surface, which is important for practical application of the results. The measurement procedure was as follows. During each test, one seed was placed on the inclined surface of the stand. Using a screw mechanism, the angle of inclination of the surface was gradually increased until the seed began to move along the painted steel surface. At the same time, the angle of the board inclination was measured using an electronic angle meter. The angle at which the seed began to slide along the surface was taken as the sliding angle and recorded. For each experimental variant, 100 repetitions were performed.

The static coefficient of friction was determined by calculation. For this purpose, the tangent of the angle at which the seeds began to slide on the surface was calculated [12]. The terminal velocity of seeds was determined using an aerodynamic test stand (Fig. 1) [12].

The aerodynamic stand for determining the terminal velocity of industrial hemp seeds is based on the interaction of a controlled airflow with the test material. The cross-sectional size of the duct was 110 mm, and its length was 2200 mm. The stand operated as follows. A sample of the material was placed on a special raw-material table made of mesh that did not reduce the airflow velocity. A fan generated an airflow directed through the duct, where an anemometer was installed to measure air velocity. The airflow was regulated by an air damper, the movement of which increased or decreased the flow velocity by opening or closing the duct. After passing the anemometer, the airflow lifted the particles of the sample placed on the table. The lifting height of these particles was measured using a ruler located in the working chamber, which had a transparent window for observing the process. For each sample, the determination of terminal velocity was repeated 50 times. The terminal velocity was recorded at an airflow regime at which about 90% of the seeds in the sample were in a suspended state. This state was assessed visually. The measurement procedure is shown in Fig. 2.

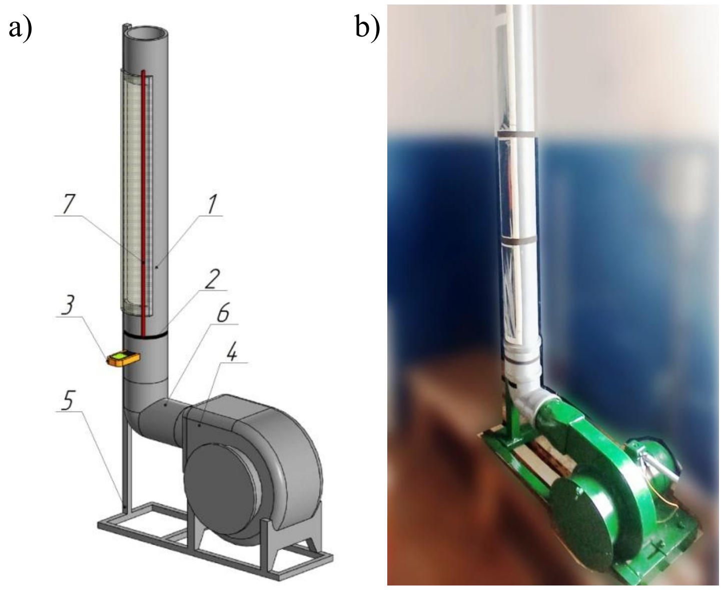

Fig. 1. **Volumetric model (a) and general view (b) of the aerodynamic test stand:** 1 – working chamber; 2 – raw material table; 3 – GM8908 anemometer; 4 – fan; 5 – frame; 6 – duct; 7 – ruler

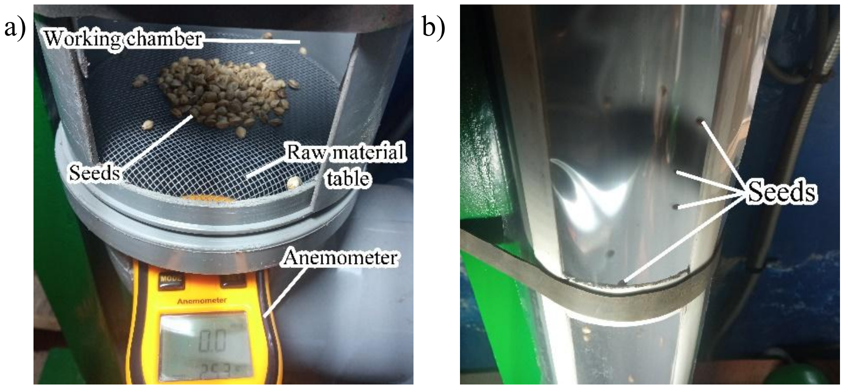

Fig. 2. **Measurement of terminal velocity:** a – sample loading; b – the process of seed suspension in the air flow

Results and discussion

Four samples of industrial hemp seeds bred by the Institute of Bast Crops (Ukraine) were used in the study. The seed samples differed in cultivar and growing location (Table 1).

Table 1

Characteristics of hemp seed samples

No.	Indicator	Unit	Values			
			Sample 1	Sample 2	Sample 3	Sample 4
1	Cultivar	-	Hlesiia	Hlukhivskyi 51	Hlukhivskyi 51	Hliana
2	Origin	-	Hlukhiv	Chernihiv	Hlukhiv	Lebedyn
3	Moisture content	%	8.4	7.4	8.4	7.3
4	1000-seed weight	g	17.46	14.13	16.27	13.85
5	Impurity content	%	1.2	18.3	10.7	19.6

Sample 1 belongs to the cultivar "Hlesiia", samples 2 and 3 represent the cultivar "Hlukhivskyi 51", and sample 4 corresponds to the cultivar "Hliana". Samples 1 and 3 were grown in the fields of the Institute of Bast Crops (Hlukhiv, Sumy region), sample 2 was grown in Chernihiv (Chernihiv region), and sample 4 in Lebedyn (Sumy region). The seed moisture content ranged from 7.3% to 8.4%. The 1000-seed weight varied from 13.85 g to 17.46 g, indicating differences in the seed size and density among the cultivars. Particular attention was paid to impurity content, which was high in samples 2 and 4 (18.3% and 19.6%, respectively).

Based on the analysis of the fractional composition of seed lots, changes in the proportion of fractions were observed: in sample 1, the coarse fraction accounted for 11.52%, the medium fraction for 63.73%, and the fine fraction for 24.75%. For sample 2, the respective values were 12.37%, 70.35%, and 17.28%; for sample 3, 17.31%, 66.12%, and 16.57%; and for sample 4, 14.45%, 54.18%, and 31.37%, respectively. The highest proportion of the medium fraction was found in sample 2, which may indicate more thorough grading.

It was noted that sample 1 had the highest 1000-seed weight: 23.51 g for the coarse fraction, 18.34 g for the medium fraction, and 13.44 g for the fine fraction, with an overall 1000-seed weight of 17.46 g. In sample 2, these values were 18.56 g, 14.45 g, and 10.89 g, respectively, with an overall 1000-seed weight of 14.13 g. In sample 3, they were 20.66 g, 16.24 g, and 11.39 g, with an overall 1000-seed weight of 16.27 g. In sample 4, the 1000-seed weight was 19.91 g for the coarse fraction, 15.94 g for the medium fraction, and 9.84 g for the fine fraction, while the overall 1000-seed weight was 13.85 g. Thus, in terms of 1000-seed weight, sample 1 exhibited the best results for all three fractions as well as for the overall 1000-seed weight.

Hemp seed size is a primary factor in fractionation, affecting grading conditions and the separation process. Information on seed dimensions makes it possible to determine the required design dimensions of openings in processing and grading equipment. In addition, understanding the effect of the seed size on processing efficiency (shelling) supports the development of new methods and technologies that improve shelling operations and reduce raw material processing time.

According to the results of the hemp seed size study, the following was noted.

- In sample 1, the coarse fraction was characterized by an average width of 3.77 mm, length of 4.79 mm, and thickness of 3.13 mm. The maximum and minimum values ranged from 4.43 to 3.09 mm for width, from 5.53 to 4.14 mm for length, and from 3.41 to 3.00 mm for thickness, respectively. The fine fraction had the following average dimensions: width 3.40 mm, length 4.49 mm, and thickness 2.70 mm. The medium fraction had smaller dimensions compared to the other fractions of this sample.
- In sample 2, the coarse fraction had slightly smaller dimensions than in sample 1. The fine fraction showed similar dimensions to the fine fraction of sample 1, with a minor difference in length. The medium fraction exhibited the smallest width among all samples.
- In sample 3, the coarse fraction had the largest maximum width (4.73 mm) compared to the other samples. The fine fraction had the smallest mean length (4.05 mm) compared to the other samples. The medium fraction had the smallest maximum length (4.50 mm).
- In sample 4, the coarse fraction had the largest mean length (5.27 mm) and the largest maximum length (5.98 mm) compared to the other samples. The fine fraction had the largest maximum width (4.20 mm) among the fine fractions of the other samples.

It was noted that the coarse fraction of sample 4 was characterized by the greatest width and length among all investigated samples. In sample 1, the medium fraction had the largest length, whereas in sample 3 it had the smallest length and width. For all samples, seed thickness was relatively stable, with only minor differences.

In sample 2, the fine fraction was characterized by the greatest thickness, while in sample 1 it had the greatest length. The smallest width and length were observed for the fine fraction of sample 3; therefore, it was classified as the smallest among the fine fractions.

Patterns of variation in industrial hemp seed dimensions depending on the soil and climatic growing conditions were established (width 2.10-4.73 mm, length 2.73-5.98 mm, thickness 1.91-3.94 mm). The complex geometric shape of the seeds and the wide range of dimensional variability, even within a single cultivar, were confirmed. It was noted that seeds from sample 1 had the highest bulk density, 537 $g \cdot L^{-1}$ (sample 2 - 448 $g \cdot L^{-1}$, sample 3 - 510 $g \cdot L^{-1}$, and sample 4 - 445 $g \cdot L^{-1}$).

Samples with higher bulk density were characterized by a higher 1000-seed weight, indicating better seed quality and potential productivity.

The sliding angle was determined for three fractions (coarse, medium, and fine) of sample 1 of the cultivar “Hlesiia”.

It was noted that the coarse seed fraction, due to the higher pressing force (normal reaction force) acting on an individual seed, generates a higher frictional force. This is consistent with studies showing that the heavier the seed, the greater the inclination angle required to initiate its motion. The established mean sliding angle was 34.10 for the coarse fraction, 30.40 for the medium fraction, and 33.30 for the fine fraction, respectively. The higher sliding angle of the fine fraction compared to the medium fraction is attributed to specific features of its surface structure.

The value of the static coefficient of friction depends on the contacting materials, their surface roughness, as well as the temperature and moisture of the surfaces. The static coefficient of friction is defined as the tangent of the angle at which a seed begins to slide on the surface [12]. The calculated values of the static coefficient of friction are presented in Table 2.

Table 2

Values of the static coefficient of friction of industrial hemp seeds of the cultivar "Hlesiia" for different seed fractions

Parameter	Coarse fraction	Medium fraction	Fine fraction
Static coefficient of friction	0.91-2.37	1.05-2.54	0.98-2.51

The mean values of the static coefficient of friction for the coarse, medium, and fine seed fractions of the cultivar "Hlesiia" were 1.48, 1.70, and 1.52, respectively. It was noted that the medium fraction exhibited the highest coefficient of friction, indicating specific features of its surface structure.

Geometric parameters and physical and mechanical properties of seeds affect their behavior in an air flow. During technological treatment (cleaning, thermal drying, active ventilation, etc.), air movement through seed layers induces various effects. At low air velocities, the seeds remain as a formed layer, while air penetrates through the pores of this layer. An increase in the air velocity causes seeds to move relative to one another. This reduces the seed concentration within the layer and increases its volume. Under such conditions, a pseudo-fluidization effect occurs; a further increase in velocity leads to pseudo-boiling, when the resistance of the air flow approaches the weight of the seeds. The gas or air flow velocity at which seeds remain suspended is termed as the terminal velocity for the given material.

During the development and fabrication of the aerodynamic test stand, experiments were conducted to select a mesh material that would not reduce the air flow velocity. Four mesh samples made of different materials were examined: sample 1 – polyethylene; sample 2 – steel; sample 3 – copper and polyethylene; sample 4 – copper.

According to the results (Fig. 3), sample 1 (polyethylene mesh) provided the best air flow velocity in the duct of the aerodynamic test stand. The air flow velocity coefficient was determined as the ratio of the air velocity in the duct with the tested mesh material present to the air flow velocity without the mesh; therefore, this indicator is dimensionless. For each experimental variant, the measurements were performed in 50 replicates.

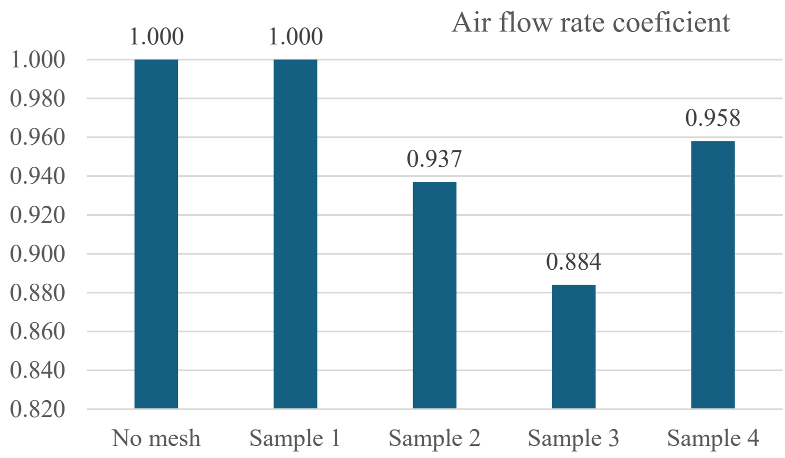

Fig. 3. **Effect of the mesh material on the air flow velocity coefficient in the duct of the aerodynamic stand**

The terminal velocity was determined for three fractions (coarse, medium, and fine) of sample 1 of the cultivar "Hlesiia". During the experiment, the pseudo-fluidization effect was identified, when seeds began to move relative to one another, as well as the terminal velocity, defined as the air velocity at which approximately 90% of the sample was in a suspended state.

For the coarse fraction of sample 1 of the cultivar "Hlesiia", the pseudo-fluidization velocity was 5.2 $m \cdot s^{-1}$, and the terminal velocity was 7.2 $m \cdot s^{-1}$, which were the highest values among all fractions. The medium and fine fractions, having lower mass and smaller dimensions, exhibited terminal velocities of 6.8 and 5.8 $m \cdot s^{-1}$, respectively.

These results indicate that larger seeds with greater mass and inertia provide higher stability in an air flow compared to smaller seeds.

Conclusions

Patterns of variation in the dimensions of industrial hemp seeds were established for the cultivars "Hlesiia" and "Hlukhivskyi 51" (grown in the fields of the Institute of Bast Crops, Hlukhiv, Sumy region), the cultivar "Hlukhivskyi 51" (Chernihiv, Chernihiv region), and the cultivar "Hliana" (Lebedyn, Sumy region): width 2.10-4.73 mm, length 2.73-5.98 mm, and thickness 1.91-3.94 mm. The seeds were found to have a complex geometric shape and a wide range of dimensional variability, even within a single cultivar.

It was noted that the highest bulk density, 537 $g \cdot L^{-1}$, was recorded for sample 1 of the cultivar "Hlesiia" (sample 2, cultivar "Hlukhivskyi 51" – 448 $g \cdot L^{-1}$; sample 3, cultivar "Hlukhivskyi 51" – 510 $g \cdot L^{-1}$; sample 4, cultivar "Hliana" – 445 $g \cdot L^{-1}$).

The mean sliding angle for the coarse fraction of the cultivar "Hlesiia" was 34.10, for the medium fraction - 30.40, and for the fine fraction – 33.30, respectively. The mean static coefficient of friction for the coarse, medium, and fine fractions was 1.48, 1.70, and 1.52, respectively. The medium fraction exhibited the highest coefficient of friction, indicating specific features of its surface structure.

For the coarse fraction of the cultivar "Hlesiia", the pseudo-fluidization velocity was 5.2 $m \cdot s^{-1}$, and the terminal velocity was 7.2 $m \cdot s^{-1}$, which were the highest among all fractions. The medium and fine fractions, having lower mass and smaller dimensions, exhibited terminal velocities of 6.8 and 5.8 $m \cdot s^{-1}$, respectively.

Author contributions:

Conceptualization, V.S. and D.P.; methodology, V.S., D.P. and D.S.; software, V.S., D.P., D.S. and O.S.; validation, V.S., D.P., D.S. and O.S.; formal analysis, V.S., D.P. and D.S.; investigation, V.S., D.P. and D.S.; data curation, V.S., D.P., D.S. and O.S.; writing – original draft preparation, V.S. and D.P.; writing – review and editing, V.S., D.P., D.S. and O.S.; visualization, V.S., D.P., D.S. and O.S.; project administration, V.S., D.P., D.S. and O.S.. All authors have read and agreed to the published version of the manuscript.

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