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STUDY ON THE AERODYNAMIC AND DIMENSIONAL PROPERTIES OF CORN USED TO OBTAIN BIOFUEL

Ioan Radu Sugar[1], Ferenc Gaspar[2]✉, Olivian Chiver[1]

[1]Technical University of Cluj-Napoca, Faculty of Engineering, Romania
[2]Technical University of Cluj-Napoca, Faculty of Automotive, Mechatronics and Mechanical Engineering, Romania
✉ferenc.gaspar@auto.utcluj.ro

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ABSTRACT

The study focuses on the determination and evaluation of aerodynamic and dimensional characteristics of Pioneer P9911 maize seeds, important for post-harvest operations. Measurements of 320 seeds from eight maize ears were used to calculate geometrical mean dimensions and aerodynamic features. At a moisture content of 14% the thousand seed weight was 360 g and hectolitre mass (HLM) of 79-84 kg/hl. Seeds average dimensions for length was 13.08 mm, width of 8.61 mm, and thickness of 5.18 mm. The results show 98.30% of seed dimensions fell within three standard deviations (STD) of the mean interval. The calculated terminal velocity of 14.53 m/s and experimental value of 16.5 m/s are above literature references. These findings offer valuable insights for configuring machinery in grain conveying, sorting, and cleaning processes.

1. Introduction

Concerns on a global level for saving fuels and finding alternatives for them, were triggered by the embargo on oil in 1973.

Thus, in the current geopolitical conditions regarding the war in Ukraine, the conflict in the Middle East, and the restrictions regarding the environment, automobile manufacturing companies are looking for new solutions. If in the last century the cars equipped with internal combustion engines prevailed over the electric ones thanks to the innovative ideas of Henry Ford in 1913, after a century the electric cars will take their revenge.

However, the researchers still have some problems to solve. From the point of view of pollution for the production of the batteries needed for electric cars, this reaches 80% of the pollution of a classic car equipped with a spark ignition engine. (Stan 2024)

Another unsolved problem is the recycling of these batteries, which, as they are not standardized and have elements that are not very friendly to the environment, require additional costs. At the level of current technology, hybrid cars seem to be the optimal solution. Biofuels have also been and will remain an alternative in countries such as Brazil, the USA or the EU. Although the cost price is sometimes higher than the price of classic fuels in periods of geopolitical crises and possible embargoes, their use can become an objective necessity. For the production of biofuels, pneumatic transport and raw material cleaning play an important role in obtaining good quality fuels.

Cereals have been vital for human sustenance since ancient times, with maize standing out as Europe's second most cultivated grain, crucial for the food industry.

The quest for high-quality maize begins with selecting appropriate varieties suited to specific cultivation regions and climates. Post-harvest processes, including cleaning, sorting, transportation, drying, and storage, are pivotal for maintaining raw material quality. Machinery used in these primary processes relies heavily on the geometrical and aerodynamic characteristics of grains to ensure high-quality end products. Understanding cereal grain properties is crucial not only for post-harvest operations but also for analyzing processes like sowing (Findura 2018, Csizmazia 2008,) and sorting in harvesting combines (Gheres 2020).

Knowledge of the physical characteristics of the seeds is also required in post-harvest machinery design processes (Liu 2022, Panwar 2023).

The physical properties (Atere 2016, Brar 2017) of grain seeds, such as dimension, humidity content, weight, bulk density, shape, depends primarily on the type of variety (Beral 2020, Darfour 2022, Markowski 2013), climatic and geographical and conditions (Mandea 2018).

The geometric dimensions of the grain define their shape which is mathematically defined by the sphericity factor (Kaliniewicz 2015). The shape of the seeds is also important influencing the aerodynamical behaviour.

The aerodynamic properties of grains and seeds affected by moisture was analysed by Chavoshgoli 2014, Gierz 2018 developed a method for aerodynamic properties measurements of crop seeds. Kumar 2020 studied the characteristics of Indian wheat crop. Aerodynamic characteristic of different cereal seeds was also studied by Matouk 2005, Nalbandi 2010 (wheat and triticale), Shahbazi 2014, Shahbazi 2015a (lentil seeds), Shahbazi 2015b (mung bean seeds). These data are important in pneumatic-based post harvesting processes (Ghafori 2011).

The terminal velocity of seeds is drag coefficient dependent. Many theoretical and experimental studies were developed on drag coefficient of seeds (Bagheri 2016, Chavoshgoli 2014, Haider 1989, Poleak 2016, Tran-Cong 2004).

For corn grown in Romania, some of the physical characteristics are presented by Stefanescu 2003: the dimensions are (5.5 – 13.5 mm) for length, width of (5.0 – 11.5 mm), thickness between (2.5 – 8.0 mm), the thousand seed weight of 130 – 380 g, bulk density of 0.68-0.82 kg/dm^3, true density of 1.3 – 1.4 kg/dm^3 and, porosity of 35-55%, and a terminal velocity of 12.5 – 14 m/s.

2. Materials and methods

The analysed maize seed was the PIONEER P9911, a semi-divided maize hybrid belonging to the Optimum AQUA max group, with excellent yield capacity. The most used hybrid by processors for the brewing industry. It reacts very well to intensive technology. It is recommended for plain and hilly areas from the south, west and east of the country of Romania (*** Catalog 2018). The thousand seed weight is 330-360 g, respectively a hectolitre mass (HLM) of 79-84 kg/hl.

To perform the statistical calculations, N=320 seeds from the studied material were measured with a digital calliper having accuracy of 0.01 mm. Three series of values for length (L), width (W) and Thickness (Th) resulted, being delimited between minimum (L_{min}, W_{min}, Th_{min}) and maximum (L_{max}, W_{max}, Th_{max}) values. The values resulting from the measurements were grouped into 10 classes and statistically analysed based on the methodology presented by Sugar et al. 2021.

The study of aerodynamical behaviour of seeds is important in the cleaning, sorting and pneumatical transportation processes.

The mathematical relation used for theoretical calculation of terminal velocity (Mujumdar 2015) is shown below:

$$v_T = \sqrt[2]{\frac{2 \cdot m_s \cdot g \cdot (\rho_g - \rho_a)}{C_d \cdot A_s \cdot \rho_s \cdot \rho_a}}\ , \text{(m/s)} \qquad (1)$$

Where $m_s=372 \cdot 10^{-6}$ kg represents the mass of a single maize seed, g=9,81 m/s^2, the density of seed ρ_s in kg/m^3 was determined with relation (2), ρ_a=1.2047 kg/m^3 is air density at 20 °C.

$$\rho_s = \frac{m_s}{V_s}\ ,\text{(kg/m}^3\text{)} \qquad (2)$$

The surface area of the seed cross section (A_s) normal to the airflow, and the seed theoretical volume (V_s) is had been calculated from equations (3) and (4).

Where the equivalent diameter of the maize (d_s) seed was calculated based on relation equation (5) considering the average values for length (M_L=13.8 · 10^{-3} m), width (M_W=8.61 · 10^{-3} m), respectively the thickness (M_{Th}=5.18 · 10^{-3} m).

$$A_s = \frac{\pi \cdot d_{gs}^2}{4}\ , (m^2) \qquad (3)$$

$$V_s = \frac{4}{3} \cdot \pi \cdot \left(\frac{d_s}{2}\right)^3, (m^3) \qquad (4)$$

$$d_s = \sqrt[3]{M_L \cdot \frac{(M_W - M_{Th})^2}{4}}, (m) \qquad (5)$$

The aerodynamic coefficient c_d can be calculated theoretically (Bagheri 2016). For this case the value of 0.5 was chosen, commonly used in specialized literature (Mujumdar 2015).

The experimental setup used for terminal velocity measurements is shown in Figure 1.

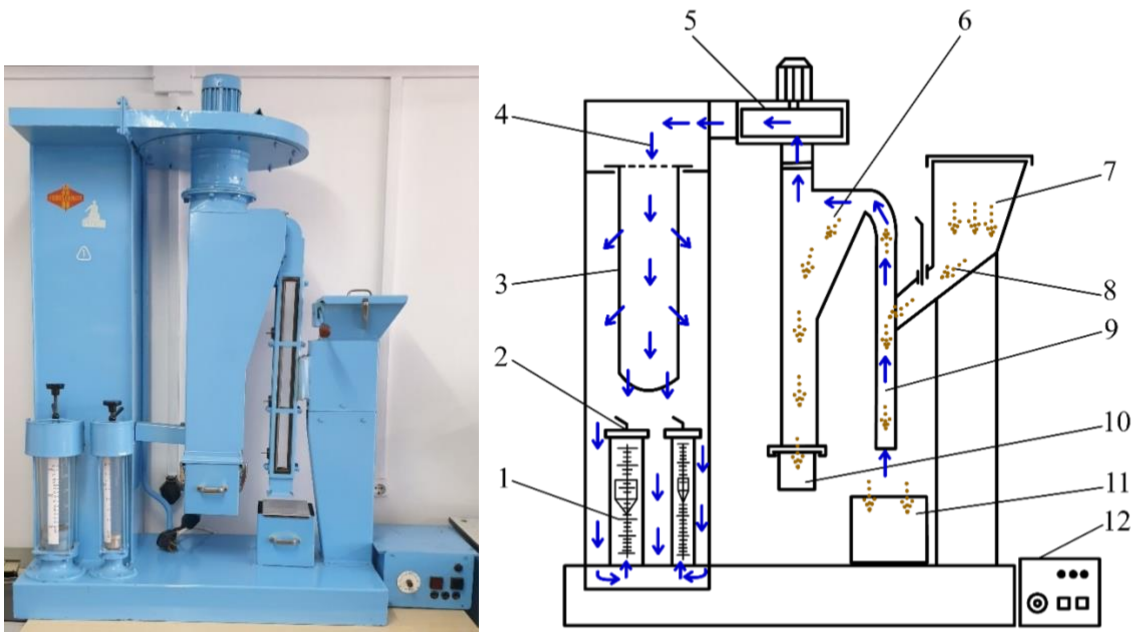


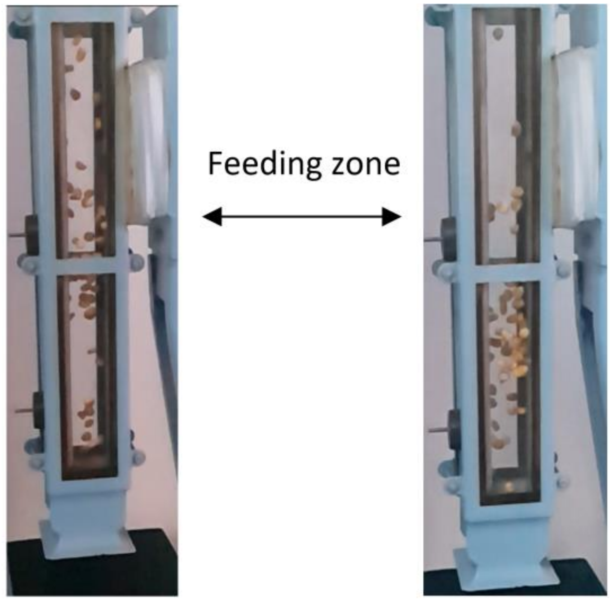
Figure 1. The experimental setup used for terminal velocity measurements:
1 – flowmeter, 2 – flow valve, 3 – bag filter, 4 – air flow, 5 – air pump, 6 – air – grain separator zone, 7 – feed hopper, 8 – grain flow, 9 – observation column, 10 and 11 – grain collectors, 12 – control box.

Maize seeds fed into feed hopper are dosed into the observation column. The air flow in the installation is provided by the centrifugal fan through the observation column, then passes through the separation zone, through the bag filter and then out through the flow meter calibrated to the air speed in the observation column. The air flow is adjusted at the flow valve.

Depending on the air velocity in the observation column, the maize seeds are lowered into seeds collector or are lifted into the separation zone. Determining the terminal velocity is possible by following the distribution of the grains in the observation column and correlating the position of the float device in the flow meter calibrated with the air speed in the observation column.

During the experimental measurements, it was found that the maize seeds start to float at the air speed of 17.5 m/s (Figure 2.b), at 19.1 m/s, a balance was observed for most of the seeds in the air tunnel (Figure 2.a).

At an air speed over 20 m/s in the observation tunnel, the effect of pneumatical transport took place.



a. b.

Figure 2. Maize seeds behaviour during the experiment.

3. Results and discussions

The extreme, and average values of dimensions, standard deviations (STD), theoretical, and experimental terminal velocity of Pioneer P9911 maize seeds are shown in Table 1.

The theoretical determined terminal velocity (for Cd=0.5) was 14.53 m/s and the empirically determined terminal velocity was 16.5 m/s with a deviation of 12%.

The average values of dimensions found for the studied Pioneer P9911 seeds correspond to the data given in the literature (Stefanescu 2003), but the maximum values are found above the limits of the range.

The average dimensions resulted were length of 13.8 mm, width 8.61 mm, respectively the average thickness found was 5.18 mm.

In the case of length size, the STD indicate a greater dispersion of values, while the values for thickness are more closely clustered around the mean. The one STD of the mean (M-σ, M+σ), two STD (M-2σ, M+2σ), and three STD of the mean (M-3σ, M+3σ) are ploted in table 2 corelated to the frequency occurrence for each dimension.

The STD of the mean show a goodcorrelation with the 68 – 95 - 99.7 rule in the case of width dimension.

Table 1. Statistical evaluation of measurements, and terminal velocity results

Dimension	D_{Max} (mm)	D_{Min} (mm)	$D_{Average}$ (mm)	STD	Terminal velocity (m/s)	
					Calculated	Experimental
Length	15.94	7.84	13.08	1.23	14.53	16.5
Width	11.02	5.56	8.61	0.90		
Thickness	8.47	3.80	5.18	0.85		

Table 2. STD of the mean and frequency occurrence of geometrical values

Dimension	(M-σ, M+σ)	Frequency (%)	(M-2σ, M+2σ)	Frequency (%)	(M-3σ, M+3σ)	Frequency (%)
Length	(13.07, 14.29)	53.77	(10.64, 15.51)	93.44	(9.42, 16.72)	98.36
Width	(7.71, 9.51)	69.51	(6.81, 10.41)	95.41	(5.91, 11.31)	99.02
Thickness	(4.33, 6.03)	79.67	(3.48, 6.88)	94.09	(2.63, 7.73)	98.36

For length dimensions, the one STD of the mean shows unexpected frequency, lower occurrence and in the case of the three STD of the mean the values are close to the 99.7%rule.

The frequency occurrence for geometrical dimension values plotted against the size range for ten dimension classes are shown in figure 3 (for length), figure 4 (for witdh) and figure 5 (for thickness).

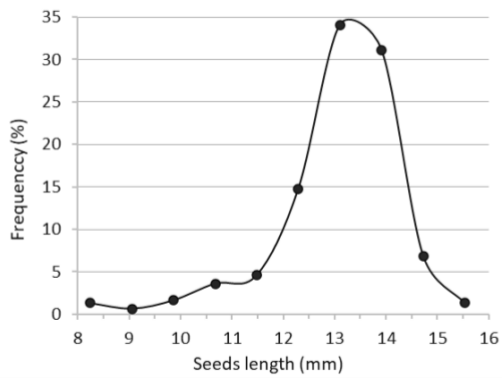


Figure 3. The distribution of lenght values across dimension classes within the size range.

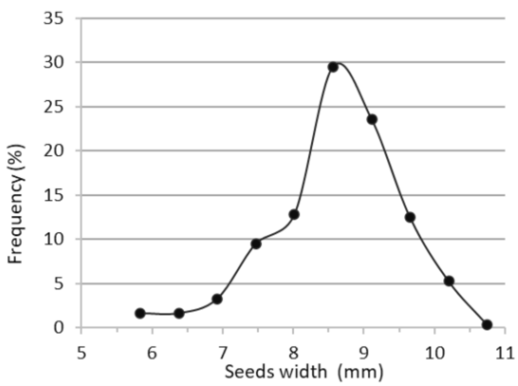


Figure 4. The distribution of width values across dimension classes within the size range

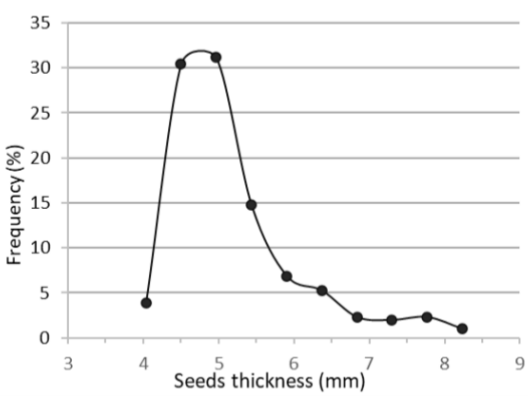


Figure 5. The distribution of thickness values across dimension classes within the size range.

In case of length values the highest occurrence of 34% is in class 7 with interval limits of (12.7, 13.51), for width dimensions the highest occurrence of 29.5% is in class 6with interval limits of (8.29, 8.84), and thickness values highest occurrence of 31% are in calss 3 having interval size limits of (4.73, 5.20).

4. Conclusions

In this study, the aerodynamic and dimensional properties of Pioneer P9911 maize seed were analysed as in pneumatic conveying, sorting, and cleaning processes the terminal velocity of seeds is an essential parameter. Average dimensions and STD values are also important in mechanical cleaning and sorting of grains in the case of choosing the size of the sieve openings.

The average value for length size was 13.08 mm with a STD of 1.23, for width the average value was 8.61 mm having a STD of 0.9, and the average thickness of 5.18 mm with a STD of 0.85 was found.

The empirical value of terminal velocity (16.5 m/s) for the studied maize seeds are closely related to the theoretically calculated (14.53 m/s), having a deviation of 12%. The Pioneer P9911 maize seeds terminal velocity is above of the given interval of (12.5, 14 m/s) found in the literature.

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