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Pneumatic conveying characteristics of seeds in a vertical ascending airstream

M. Kroulík, J. Hůla, A. Rybka, I. Honzík

Department of Agricultural Machines, Faculty of Engineering, Czech University of Life Sciences Prague, Prague, Czech Republic

Abstract

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Pneumatic conveying characteristics were measured in vertical tubes for seeds of selected varieties of cereals, wide-row crops, oil crops, legumes and catch crops. The measured values were used for graphical representation of variation curves for the chosen groups of seeds. The values of the critical air velocity for seeds (velocity of seed lift) were computed. Statistical significance of differences in the mean values of critical velocities of tested seeds was determined. The critical velocity of cereal seeds ranged from 8.03 to 10.54 m/s. Among the crops grown in wide rows the highest critical velocity of seeds was found out in maize (13.29 m/s), the lowest in sunflower seeds (8.38 m/s). In oil crop seeds, the lowest critical velocity was recorded in poppy (4.67 m/s), which was the lowest value of all seed samples of the tested crops. The highest value of the critical velocity was measured in pea seeds (14.85 m/s).

Keywords: sowing machines; aerodynamic properties of seeds; variation curves

Aerodynamic properties of seeds represent the behaviour of seeds in airstream. They are mainly related to seed properties (weight, shape, surface), and also to the condition of the air environment – airflow evenness (Srivastava et al. 2006). The knowledge of aerodynamic properties of grains is applied to the design of grain cleaning and sorting systems as well as to the construction of the pneumatic sowing mechanism of seed drills.

The seeds placed in a central hopper of the seed drill are sliding by gravity and by help of an opener to a vane turnstile that delivers them fluently to the airstream from the fan. The seeds are then conveyed by the airstream pressure usually in a vertical direction upwards to a distribution head and then horizontally or obliquely through delivery tubes to drill coulters.

The vertical delivery of seeds upwards is a limiting feature for the appropriate function of the sowing mechanism; it is possible only when the volume flow rate of air (m^3/s) and its velocity (m/s) are chosen in such a way that the airstream will convey the seeds evenly. This air velocity should be higher than so called critical velocity of seeds (velocity of seed lift) and should include a reserve for the potential increased mass flow of seeds associated with the required change in specific seeding rate. The upper limit of the air velocity is a requirement to avoid seed damage in the course of its conveyance.

It follows from the experiments conducted in the past (Neubauer et al. 1986; Páltik et al. 2003) that the air velocity (v_a) in the vertical duct should be chosen in the range:

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$$v_d \geq v_a \geq v_{cr} \quad (1)$$

where:

v_d – air velocity at which seed damage begins to be visible (m/s)

v_a – air velocity (m/s)

v_{cr} – critical velocity (lift velocity) of seeds (m/s)

With the growing demands for precision seeding and seed placement of sown crops, especially cereals and oilseed rape, it is necessary to critically reconsider the requirements for seeds transporting in the seed pipe. It will also be necessary to take into account the energy consumption for ventilator drive and change diameters of seed pipes. Güner (2007) determined that the terminal velocities for wheat, barley, sunflower, and lentil varied from 9.86 to 10.27 m/s, 7.44 to 8.25 m/s, 6.13 to 6.61 m/s, and 6.99 to 7.72 m/s, respectively. As Güner (2007) reported, when air alone was blown, the pressure drop and the power requirement increased with the air velocity. As an important requirement for a limiting air velocity there is the risk of seeds damage and loss of important properties for seed. The danger of mechanical damage for all seeds increased with increasing air velocity. Germination and vigour index decreased when the conveying velocity increased.

Starting points for measurements of aerodynamic characteristics of seeds and mineral fertilizers were formulated by Stroshine (2000), Csizmazia and Polyak (2001) and Güner (2007). Aerodynamic properties of wheat grain were studied by Khoshtaghaza and Mehdizadeh (2006). Critical air velocity for seeds of forest trees was found out by Tylek and Walczyk (2003). If the air velocity is chosen, the sown seeds gain a velocity in the vertical tubes that is given by a difference between the air velocity (v_a) and their critical velocity (v_{cr}). For each kind of seed an optimum air velocity (v_a) exists which should correspond with seed homogeneity (weight, shape, surface) in order to ensure the fluent flow of seed to drill coulters.

The seed with critical velocity (v_{cr}) conveyed to the vertical air duct with the air velocity $v_a \geq v_{cr}$ will move upwards at the resultant absolute velocity (v_{abs}). Maximum velocity of each single seed ($v_{abs\ max}$) is given by a difference between the airstream velocity (v_a) and the critical velocity of seed (v_{cr}). It means that within the airstream with its constant velocity each seed with different critical velocity moves at different absolute velocity (v_{abs}), so particular seeds mutually hit each other and influence their movement, which results in the irregular delivery of seeds to drill coulters.

If the seed delivery to the air duct is irregular (clustered), the quality of air conveying and the seed distribution to the particular outlets in the distribution head are deteriorated (Heege 1970; Mahlstedt 1972).

The objective of the experiment was to define values of critical vertical velocities of seeds and the seeds variation curves of selected crops according to the vertical velocities, to evaluate parameters of their non-homogeneity and to determine statistical significance of the differences of critical velocities of seeds.

MATERIAL AND METHODS

Seed samples acquired from the Oseva Uni a.s. company and samples supplied by the experimental station of the Faculty of Agrobiology, Food and Natural Resources affiliated to the Czech University of Life Sciences in Prague were used to measure aerodynamic properties of seeds. A laboratory K-293 air sorting machine (VEB Kombinat Fortschritt; Anlagenbau Petkus, Wutha, Germany) with the adjustable flow volume of air streaming through the vertical aspiration duct of the sorting machine was used for these measurements (Fig. 1). Four repeated measurements were done in all seed samples. Weight of each sample was 200 g. The whole sample was sorted gradually by increasing air velocity of about 0.55 m/s in the range from

Fig. 1. A part of the laboratory K-293 air sorting machine with the vertical aspiration duct

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5.55 to 16.55 m/s. The separated part was weighed, and the residue was re-sorted by higher air velocity. The values of the critical velocity of seeds (velocity of seed lift) were computed:

$$v_{\mathrm{cr}} = \frac{\sum (m_{\mathrm{i}} \times v_{\mathrm{i}})}{m} \quad (2)$$

where:

v_{cr} – critical velocity of seeds (velocity of seed lift) (m/s)
m_{i} – weight of the respective class (g)
v_{i} – velocity of the class centre (m/s)
m – weight of seed sample (g)

The measured values were used in the graphical representation of variation curves for the chosen groups of seeds expressed as % of sample weight. The critical velocity is approximately identical with the most frequent class of variation curve (assuming the normal distribution of frequencies).

Measurements were methodically based on the knowledge of aerodynamic properties of seeds of field crops (Jech et al. 2011; Russo 2011). The measured data were processed by methods of experimental statistics, using the Statistica 10 (StatSoft, Inc., Tulsa, USA). Descriptive statistics were subsequently computed for the values of the critical velocity of air. The description of the values of the studied sets is determined by arithmetical mean and median. The description of variability around the mean value is defined by the parameter of variance and standard deviation. The evaluation of the mean values reveals obvious differences. Analysis of variance was used to test significance of the differences in the mean values of critical velocities.

RESULTS AND DISCUSSION

Table 1 shows an overview of the crops, the seeds of which were selected for measurements. Besides the seed of crops planted in narrow rows, the crops in which precision drilling is used were included. Moisture content of seed ranged from 8.3% wet basis (w.b.) values to 14.0% w.b. The lowest values were measured for oilseeds, the highest values for cereals. According to Aydin (2007), as the moisture content increased, the terminal velocity for kernel and peanuts was found to increase linearly. The terminal velocity increased linearly from 7.25 to 8.06 m/s as the moisture content increased from 4.85 to 32%

Table 1. Crops and varieties in which the pneumatic conveying characteristics were determined

Crop	Variety	Thousand seeds weight (g)
Spring wheat (*Triticum aestivum* L.)	Saxana	42.1
Winter wheat (*Triticum aestivum* L.)	Darwin	45.6
Spring barley (*Hordeum vulgare* L.)	Blaník	45.2
Winter barley (*Hordeum vulgare* L.)	Luxor	47.2
Winter triticale (× *Triticosecale* Wittm.)	Pawo	44.7
Winter rye (*Secale cereale* L.)	Aventino	38.2
Oat (*Avena sativa* L.)	Korok	32.1
Naked oat (*Avena nuda* L.)	Izák	27.9
Maize (*Zea mays* L.)	CE 220 H	312.5
Sugar beet (*Beta vulgaris* L. var. *altissima* Döll)	Gaucho	28.1
Sunflower (*Helianthus annuus* L.)	LG 55.28	52.9
Sorghum (*Sorghum* Moench.)	Express	23.6
Winter rape (*Brassica napus* L. *var. napus*)	Hornet	5.6
White mustard (*Sinapis alba* L.)	Polárka	7.7
Poppy (*Papaver somniferum*)	Opal	0.51
White lupine (*Lupinus albus* L.)	Amiga	241.3
Field pea (*Pisum sativum,* conv. *Speciosum* Alef.)	Arvika	215.0
Soya (*Glycine soja* L.)	Merlin	185.7
Pea (*Pisum sativum* L.)	Zekon	247.2
Phacelia (*Phacelia tanacetifolia* Benth.)	Větrovská	2.4

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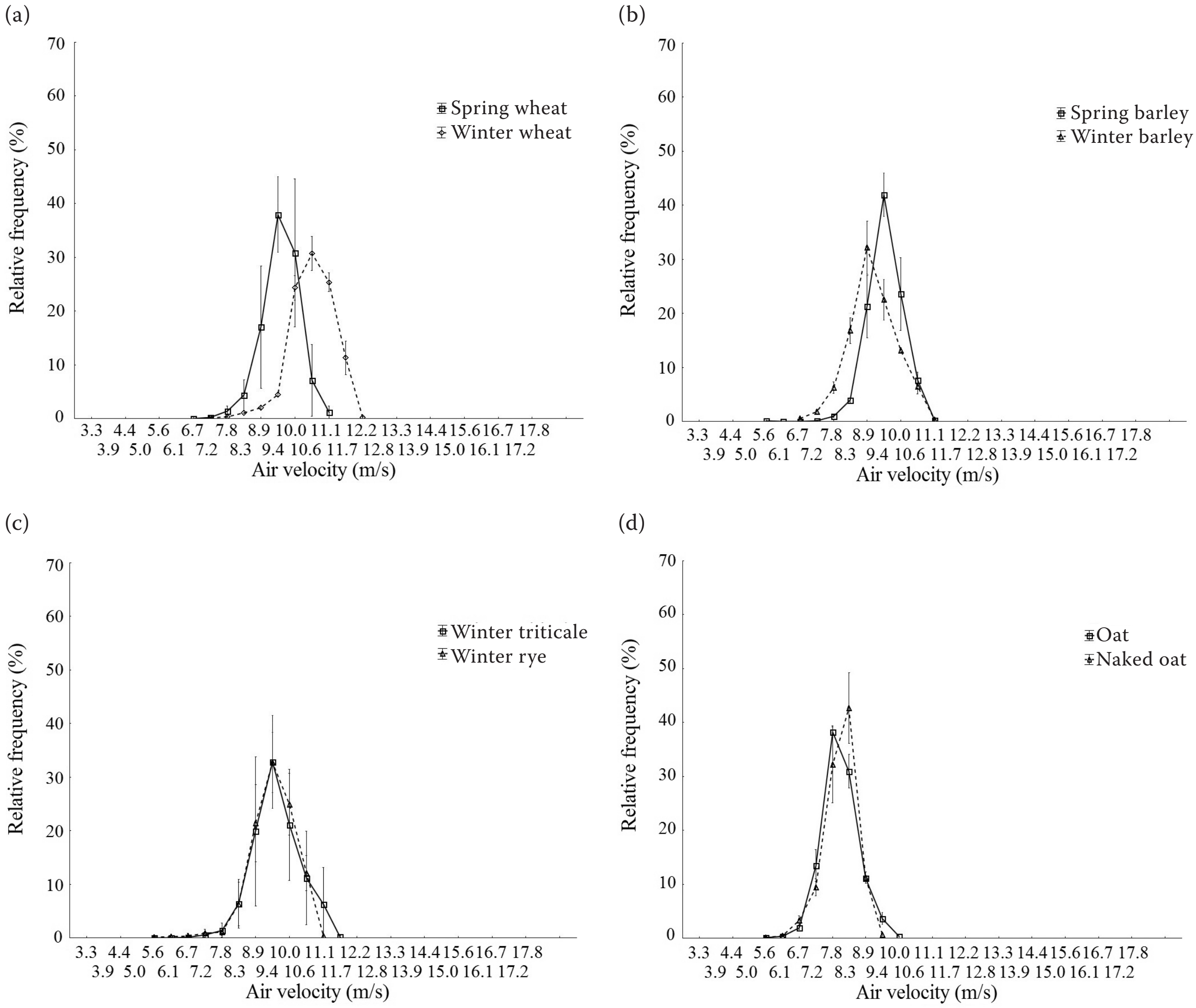

Fig. 2. Variation curves for seeds of (a) spring wheat and winter wheat, (b) barley and winter barley, (c) winter triticale and winter rye and (d) oat and naked oat

dry basis (d.b.). The relationship between moisture content (Mc) and terminal velocity (V_t) for kernel can be represented by following equation: V_t = 0.029Mc + 7.34, (R^2 = 0.99). Samples were stored in accordance with the requirements for the storage of seeds. In order to minimize changes in critical velocity in the range of grain moisture content, the effect of moisture on vertical velocity change was not monitored. Figs 2 and 3 illustrate variation curves for the groups of crop seeds, which characterize the percentage of the individual fractions sorted in vertical air velocity while increasing the air velocity by 0.55 m/s. To make graphs transparent, the scales of axes are identical in all figures. White mustard is shown in two figures: as oil crop and as commonly grown catch crop. The outputs from measurements were divided into groups to obtain clearly arranged graphs: cereals, wide-row crops, oil crops, legumes and catch crops.

Tables 2 to 4 document descriptive statistics of critical vertical velocities for seed of the particular crops. The coefficient of variation (CV) as a relative value of the measure of dispersion of values around the mean value makes it possible to compare different sets of measurement data. The coefficients of variation range from 0.36 to 7.91%. The values of the minimum and maximum define the categories the statistical sets of data belong to. The coefficient of asymmetry (skewness) quantifies asymmetry from the Gaussian normal distribution. The condition of data normality is fulfilled when the skewness interval lies between the values –2 and 2. Distribution normality was fulfilled in all cases, so one of the basic preconditions for

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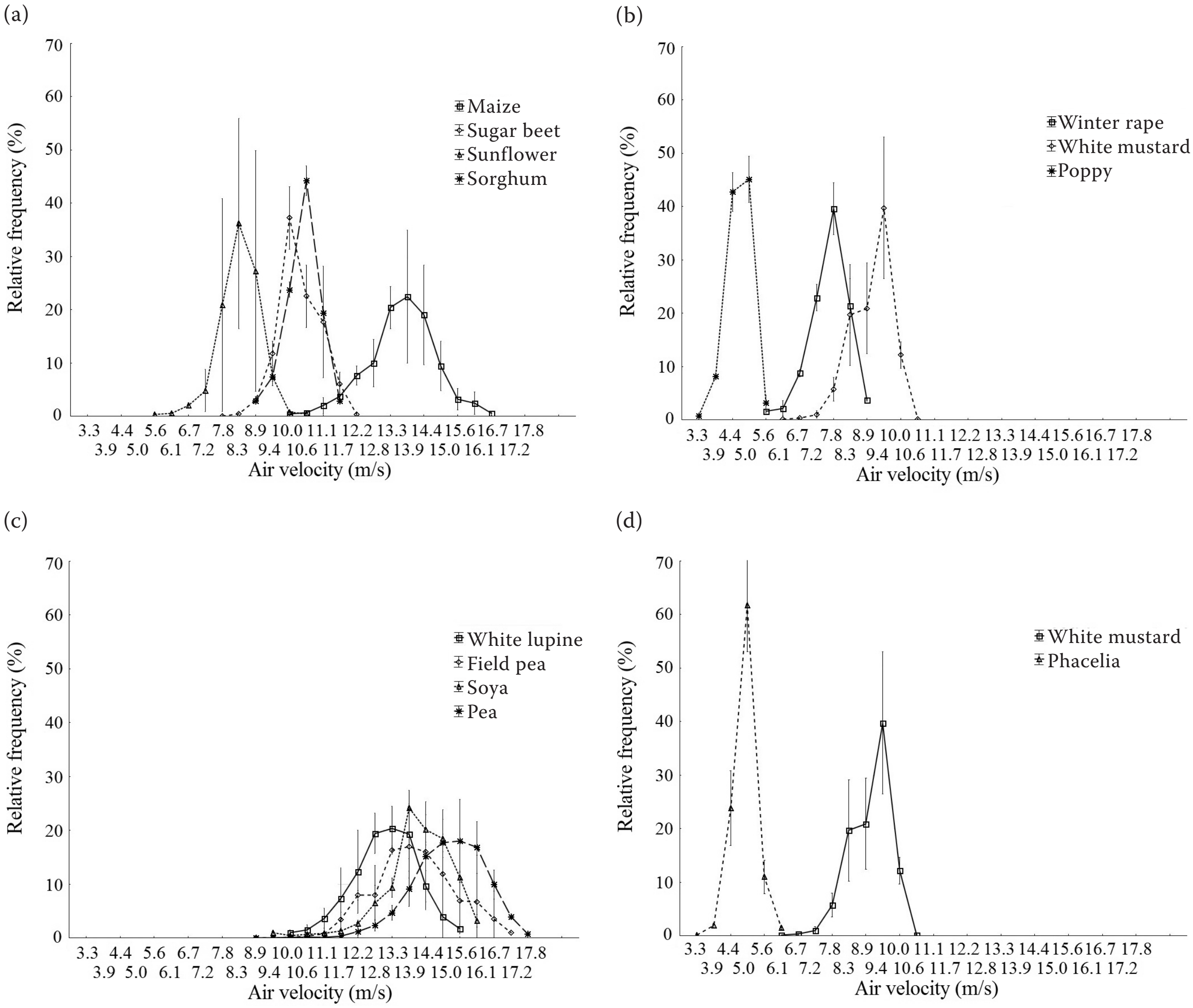

Fig. 3. Variation curves for seeds of (a) wide-row crops, (b) oilseeds, (c) legumes and (d) intercrops

the use of the majority of statistical analyses was fulfilled.

For the investigation of seed in the airstream and/or for the determination of requirements for the values of air velocity in the particular seeds, statistical significance of differences in the mean values of critical velocities was evaluated by the analysis of variance. Based on the *F*-test, statistically significant differences were found out between the values of critical velocities for the particular seeds. Table 5 shows a detailed evaluation of the analysis of variance of critical vertical velocities for all kinds of seeds. This table documents what values of the critical velocities of air are significantly different. The *T*-method was used for more detailed evaluation. The means of the values are presented in ascending order. The means designated by asterisks in the same column are not statistically different (on the chosen significance level $\alpha = 0.05$). Asterisks in different columns indicate significantly different means.

An important precondition of the analysis of variance is homogeneity of variances for all variants. Based on the performed test, variances can be considered as insignificantly different. So the results of the analysis of variance are not encumbered with an error that would be caused by non-homogeneity of variances.

Table 5 documents that the measured critical value of cereal seed was in the range of 8.03 (oat) to 10.54 m/s (winter wheat). Among the crops grown in wide rows the highest critical velocity of seed was found out in maize (13.29 m/s), the lowest in the sunflower seed (8.38 m/s).

As for oil crops, the lowest critical velocity was measured in seeds of poppy (4.67 m/s), which was

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Table 2. Descriptive statistics of critical vertical velocities for the variables Cereals

Indicator	Spring wheat	Winter wheat	Spring barley	Winter barley	Winter triticale	Winter rye	Oat	Naked oat
Mean (m/s)	9.54	10.54	9.44	9.06	9.55	9.53	8.03	8.70
Median (m/s)	9.54	10.55	9.44	9.05	9.56	9.53	8.03	8.68
Standard deviation (m/s)	0.29	0.04	0.06	0.05	0.39	0.15	0.03	0.69
Variance (m/s)	0.08	0.00	0.00	0.00	0.15	0.02	0.00	0.47
Coefficient of variation (%)	3.01	0.36	0.68	0.58	4.04	1.60	0.33	7.91
Skewness	–0.06	–0.49	0.31	1.13	–0.04	–0.21	–0.35	0.03
Difference max-min (m/s)	0.65	0.08	0.15	0.12	0.91	0.52	0.06	1.41
Minimum (m/s)	9.18	10.50	9.37	9.02	9.08	9.26	8.00	8.04
Maximum (m/s)	9.83	10.58	9.52	9.14	9.98	9.78	8.05	9.45

Table 3. Descriptive statistics of critical vertical velocities for the variables Wide-row and Oil crops

Indicator	Wide-row crops				Oil crops		
	maize	sugar beet	sunflower	sorghum	winter rape	white mustard	poppy
Mean (m/s)	13.29	10.24	8.38	10.43	7.65	9.02	4.67
Median (m/s)	13.42	10.23	8.35	10.42	7.65	8.96	4.67
Standard deviation (m/s)	0.43	0.05	0.20	0.05	0.05	0.17	0.02
Variance (m/s)	0.19	0.00	0.04	0.00	0.00	0.03	0.00
Coefficient of variation (%)	3.26	0.52	2.40	0.46	0.62	1.93	0.46
Skewness	–1.39	0.28	0.77	1.30	0.17	1.56	–0.77
Difference max-min (m/s)	1.26	0.12	0.46	0.11	0.09	0.38	0.05
Minimum (m/s)	12.40	10.18	8.19	10.39	7.61	8.89	4.64
Maximum (m/s)	13.66	10.30	8.65	10.50	7.70	9.27	4.69

the lowest value among all seed samples of the tested crops. The highest value of the critical velocity was recorded in pea seed (14.85 m/s). The phacelia seed (catch crop) was characterized by the low value of the critical velocity (4.90 m/s), which is close to the value measured in poppy.

A comparison of the measured values of the critical velocity of seeds with data in literary sources shows that the measured values of cereal, maize and pea seed are in the range of the given values. Páltik et al. (2003) reported moderately lower values of the critical velocity of cereal, maize and pea

Table 4. Descriptive statistics of critical vertical velocities for the variables Legumes and Catch crops

Indicator	Legumes				Catch crops
	white lupine	field pea	soya	pea	phacelia
Mean (m/s)	12.87	12.41	13.84	14.85	4.90
Median (m/s)	13.09	12.39	13.83	14.87	4.90
Standard deviation (m/s)	0.50	0.35	0.11	0.19	0.04
Variance (m/s)	0.25	0.12	0.01	0.04	0.00
Coefficient of variation (%)	3.85	2.81	0.81	1.28	0.89
Skewness	–1.95	0.43	0.29	0.25	–0.03
Difference max-min (m/s)	1.04	0.84	0.26	0.53	0.09
Minimum (m/s)	12.13	12.02	13.71	14.62	4.86
Maximum (m/s)	13.17	12.86	13.98	15.15	4.95

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Table 5. Schematic representation of homogeneous groups of the values of critical velocities of air – more detailed evaluation of the analysis of variance

Crop	Velocity of air (m/s)											
Poppy	4.67	****										
Phacelia	4.90	****										
Winter rape	7.65		****									
Oat	8.03		****	****								
Sunflower	8.38		****	****	****							
Naked oat	8.70			****	****							
White mustard	9.02				****	****						
Winter barley	9.06				****	****						
Spring barley	9.44					****	****					
Winter rye	9.53					****						
Spring wheat	9.54					****						
Winter triticale	9.55					****	****					
Sugar beet	10.24						****	****				
Sorghum	10.43							****				
Winter wheat	10.54							****				
Field pea	12.41								****			
White lupine	12.87								****	****		
Maize	13.29									****	****	
Soya	13.84										****	
Pea	14.85											****

*indicates significantly different means different (on the chosen significance level α = 0.05)

seed than are the values measured by the laboratory K-293 air sorting machine. Stroshine (2000) presents slightly lower values of critical speed of barley (7.3 to 9.0 m/s), maize (9.8 to 11.3 m/s) and soya (11.2 to 12.0 m/s) than the measured value. The measured critical speeds of wheat and oats are in the range of values found by Stroshine (2000).

CONCLUSION

Variation curves of the critical velocities of the main kinds of seeds indicate the degree of non-homogeneity of aerodynamic properties of seed. The result is uneven placement of seeds into the soil by seed drills with pneumatic sowing mechanisms – irregular spacing, and/or formation of clusters. It is particularly crucial with the present trend of decreasing specific seeding rates, mainly of cereals and oilseed rape, because producers require more regular distances of seeds in the soil and optimum nutritive area aimed to reach high yields. The results are applicable as background data for the construction of pneumatic sowing mechanisms of seed drills and as an argument for the improvement of seed sorting quality.

References

Aydin C. (2007): Some engineering properties of peanut and kernel. Journal of Food Engineering, 79: 810–816.

Csizmazia Z., Polyak N.I. (2001): Movement of particles in the air. Journal of Agricultural Sciences 1. Acta Agraria Debreceniensis: 22–26.

Güner M. (2007): Pneumatic conveying characteristics of some agricultural seeds. Journal of Food Engineering, 80: 904–9013.

Heege H.J. (1970): Verfahren der Breitsaat des Getreides. Grundlagen der Landtechnik. Düsseldorf: 82.

Jech J. et al. (2011): Stroje pre rastlinnú výrobu 3. Prague, Profi Press: 368.

Khoshtaghaza M.H., Mehdizadeh R. (2006): Aerodynamic properties of wheat kernel and straw materials. Agricultural Engineering International: CIGR Ejournal, FP 05007, Vol.VIII: 1–10.

doi: 10.17221/32/2014-RAE

Mahlstedt J. (1972): Pneumatische Saatgutzuteilung bei Sämaschinen für Getreide Breitsaat. KTBL – Berichte über Landtechnik, 145: 94.

Neubauer K. et al. (1986): Stroje pro rostlinnou výrobu III.. Prague, VŠZ.

Páltik J., Findura P., Polc M. (2003): Stroje pre rastlinnú výrobu – Obrábanie pôdy, sejba. Nitra, SUA in Nitra.

Russo G.P. (2011): Aerodynamic measurements. Cambridge, Woodhead Publishing.

Srivastava A.K., Goering C.E., Rohrbach R.P., Buckmaster D.R. (2006): Engineering principles of Agricultural Machines. 2nd Ed. St. Joseph USA, Asabe.

Stroshine R. (2000): Physical properties of agricultural materials and products. Purdue University, Indiana: 265–272.

Tylek P., Walczyk J. (2003): Critical air velocity as separation feature in nuts of European beech (*Fagus sylvatica* L.). Electronic journal of polish agricultural universities, 6: 4. Available at http://www.ejpau.media.pl/volume6/issue2/forestry/art-04.html

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Corresponding author:

doc. Ing. Milan Kroulík, Ph.D., Czech University of Life Sciences Prague, Faculty of Engineering, Department Agricultural Machines, Kamýcká 129, Prague 6-Suchdol, 165 21, Czech Republic;
e-mail: kroulik@tf.czu.cz