RESEARCH IN CLEANING AND SORTING OF ECOLOGICALLY GROWN WHITE MUSTARD SEED

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Abstract. The research objective was to obtain a high quality sowing material of ecologically grown white mustard (*Sinapis alba*) seed. In order to achieve the goal white mustard seed was sorted into fractions based on seed rigidity thus minimizing the amount of weed seed – field mustard (*Sinapis arvensis*) and rambling smartweed (*Polygonum convolvulus*) which have similar physical and aerodynamic characteristics to the white mustard. For the purpose of the experiment a basic stationary experimental stand was built. The unit was comprised of: 1) a frame of 3 m height; 2) a seed feed hopper with an adjustable valve; 3) an inclined plane which inclination angle to the horizon was adjustable; and 4) 0.2 m wide and 1.5 m long troughs designed for sorted seed groups. White mustard seed freely fell from the supply tank from the height of 0.5; 1.0; 1.5 and 2.0 m onto an inclined plane with an adjustable inclination angle to the horizon of 25; 30 and 40 degrees. Two types of inclined plane surface were used in testing: wooden and metallic. During the testing white mustard and weed seed was sorted into 7 fractions. With increasing the number of fraction (seed displacement with respect to the horizontal axis), the weight of 1000 seeds (g) and seed density ($kg \cdot m^{-3}$) was found to increase, however part of higher density seeds (%) was found to decrease. With increase in the number of fraction, the proportion of weed seeds in fractions was decreasing. Optimal results in the research were achieved with 1.24 $kg \cdot min^{-1}$ white mustard seed flow being supplied from the height of 2.0 m onto a metal plate with the inclination angle to the horizon set to 30º. Seed germination energy (%) and seed germination power (%), when compared to the control, did not decrease and starting with fraction 2 and onwards increased by approx. 10 % (in absolute values).

Keywords: white mustard, seed cleaning-sorting, rigidity, density, weed seed, seed germination.

Introduction

White mustard is well known and recently increasingly cultivated in Lithuania. In industrial applications white mustard is seen as an oil plant as its seeds contain 30 to 40 % of fats and 0.5-1.1 % of essential oils. In arable farming mustard is known as a plant used for producing green manure. Green mass of mustard with respect to its effectiveness is equivalent to straw manure, and with respect to its nutritional value – clover and oats/vetch mix [1]. When harvesting ecologically grown white mustard (*Sinapis alba*) seed yield, a high amount of unwanted weed seed types are collected together with threshed seeds of cultivated plants. Most weed seed types can be separated by initial machine cleaning by the help of sieves and the air flow. However, such separation is not possible without a significant loss of cultivated crop seeds with two types of weed seed – field mustard (*Sinapis arvensis*) and rambling smartweed (*Polygonum convolvulus*), which have similar physical and aerodynamic characteristics to the white mustard [2; 3].

The quality of agricultural crops sowing material is determined based on its cleanliness and biological uniformity, whereas quality improvement is always associated with the use of new sorting facilities. Since direct separation of biologically most valuable seeds is not feasible, seeds are sorted based on some physico-mechanical features that best reflect these desirable characteristics. Such features can be as follows: the dimensions of seeds, mass, shape, density, colour, frictional characteristics of their surface, etc.

Seed sorting based on seed dimensions is performed using stamped sieves and trieurs [4]. Based on their density, seeds of different plants can be sorted while soaked in water or salt solutions. For the purpose of sorting Hagner and Wend [5] used 3-5 % sodium chloride ($NaCl$) solution and potassium chloride (KCl) solution, where the fraction that came to the top of the liquid has been poured off together with the solution, whereas the sunken fraction containing seeds with higher density has been washed with water and dried. This is a highly energy-consuming process. Seed sorting based on their density can also be accomplished using gravity separators [6], and based on their aerodynamic characteristics seeds can be sorted into fractions using various pneumatic separators [7; 8] as well as aerodynamic separators [9; 10]. The latter has no sieves whatsoever which enables to avoid vibrations and offers increased technical reliability.

There are plenty of seed sorting experiments accomplished using various corona treatment and electrostatic field electro-separators that sort seeds based on the set of their mechanical and electrical characteristics. It enables to separate the biologically valuable seed of the highest quality. Such separators are versatile as they can be used for sorting seeds of diverse plants. The aforementioned machines do not cause damage to seeds as they do not contain any pointed or sharp operating parts, whereas their operating surfaces are covered with an insulation material. Machinery with electric fields not only serves to clean, sort and stimulate seeds, but also remove microorganisms from their surface [11-15].

Seed sorting can be performed using a photoelectric technique [16]. German company *Sortex* produces a sorting machine *Sortex Z* that performs seed cleaning-sorting based on optical characteristics of seeds. Hamid G. has patented a machine operating on the basis of a similar principle [17] that not only sorts seeds depending on their colour but also is capable of scanning the shape of a seed by the help of special cameras. This way any split or otherwise damaged seeds are separated and eliminated.

The aforementioned machinery involving different techniques of seed sorting are relatively expensive and intended for industrial applications as well as for large scale seed cleaning and sorting that is further consumed by large farms. Meanwhile, for the purpose of handling small amounts of seeds of ecologically grown alternative plants including seeds of white mustard basic means can be adopted. This can be achieved by cleaning-sorting seeds based on their rigidity using a stationary experimental stand of simple structure.

The objective of the research was to obtain a high quality sowing material of ecologically grown white mustard seed harvested using a combine-harvester, matching the requirements applicable for first-class sowing material quality.

Materials and methods

The subject of the research – white mustard seed of *Braco* variety and a stationary experimental stand for seed sorting into fractions based on their rigidity (Fig. 1).

White mustard was cultivated in the ecological farm located in Raseiniai district (Lithuania). The seed yield was harvested using the *Don-1500* combine-harvester. The research was performed in the Testing laboratories of technological processes of agricultural machinery of the Institute of Agricultural Engineering and Safety of Aleksandras Stulginskis University (Lithuania).

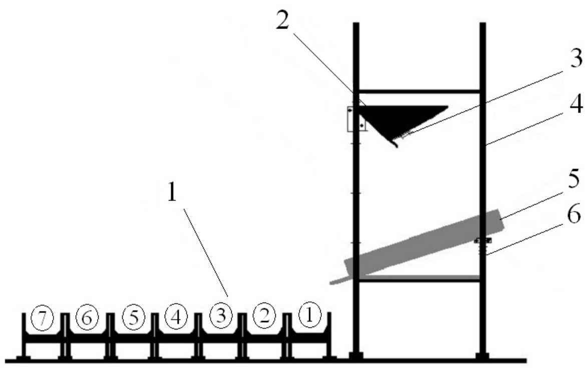

Fig. 1. **Schematic view of the stationary experimental stand used for seed sorting based on their rigidity:** 1 – troughs designed for sorted seed fractions; 2 – seed feed hopper; 3 – adjustable valve; 4 – frame; 5 – inclined plane; 6 – inclination adjustment mechanism

The seed moisture content was determined by means of drying the seed samples at 105 ºC temperature until the constant moisture content was achieved [18]. Seed cleanliness was determined based on the Standard [19] in three repetitions. Weight of each sample – 50 g. Weight of 1000 seeds was found by calculating them in bunches of 500 seeds and multiplying their weighed mass by two. Seed germination energy and seed germination power were determined based on the requirements of the standard in wet medium, using *Petri* dishes, filter paper, water and a heating oven for maintenance of temperature in the range of + 20 ºC to + 30 ºC [20].

The stationary experimental stand (4) was comprised of a supply tank (seed feed hopper) (2) attached to it with an adjustable valve (3) for the purpose of varying the intensity of seed passing through. An inclined plane with an adjustable inclination angle to the horizon α was attached to the frame. Experimentation involved inclination angles to the horizon of 25; 30 and 40 degrees. The distance from the supply tank output trough to the centre of the inclined plane was adjusted by shifting the vertically sliding bars on the frame. For the purpose of experimentation this distance was adjusted at intervals of 0.5 m by setting it as follows: 0.5; 1.0; 1.5 and 2.0 m.

The course of testing: the seeds were poured into the seed feed hopper after pre-setting its adjustable valve at the desired rate of seed pass through. Flowing seeds fell on the centre of the inclined plane and, depending on the seed density, bounced to the troughs located closer or further (1). This way mustard seeds were sorted into 7 fractions. Experimentation time (duration of seed flowing) was measured using the electronic timer *LS 3193* with the precision of ± 0.01 s. The inclination angle to the horizon of the inclined plane was measured using *BOSCH* digital spirit level *DNM 60L* with the precision of 0.1°. The seeds sorted to fractions were weighed using the *SPO 51 SCALTEC* scale with the precision of ± 0.01 g, and maximum weight capacity – 310 g. Higher amounts of seeds were weighed using the *SB 16001 (METTLER TOLEDO)* scales with precision of ± 0.1 g, and weight range of 5.0 g to 16.1 kg.

The research findings were assessed using the methods of dispersion and correlation-regression analysis. Arithmetic averages, their standard deviations and confidence intervals at 0.95 probability level were found [21].

Results and discussion

In the ecological farm white mustard of *Braco* variety has grown to a height of 79-86 cm, however weed infestation in the stand of mustard was in the range of 16-45 %. Consequently, the harvested yield was also low – approx. 220 $kg{\cdot}ha^{-1}$ (Table 1). The white mustard seed yield was harvested using a combine-harvester. Seed cleanliness in the grain tank of the combine-harvester amounted for 95.54 ± 0.32 %, and moisture content – approx. 18 %. Pre-cleaning of seeds using sieves and the air flow caused the seed moisture content to decrease to 11-12 %.

Analysis of white mustard biometric parameters showed the first lateral shoots on the main stem of a plant, when measuring from the surface of the soil, were in the height of 43-53 cm. Consequently, white mustard that even medium laid-down flat can be harvested by combine-harvesters while leaving stubble of 30-35 cm height on he soil. This results in lower loads being applied on the threshing apparatus with the mass to be threshed, and less dwarfed weeds will be collected into the combine-harvester.

The moisture content of white mustard seed harvested by the combine-harvester amounted for 17.94 ± 0.28 %, and seed cleanliness in the grain tank of combine-harvester – 95.54 ± 0.32% (Table 1).

Table 1

Biometric indicators and technological characteristics of ecologically grown white mustard

Serial No.	Parameters and measurement units	Values
1	Plant height, cm	82.11 ± 3.55
2	Plant density per unit of area, units per m^{-2}	88.00 ± 18.91
3	Distance from the soil surface to the first lateral shoot, cm	47.77 ± 4.73
4	Weed infestation from the surface of the soil, %	30.59 ± 14.14
5	Weight of 1000 seeds, g	5.71 ± 0.03
6	Seed yield, $t{\cdot}ha^{-1}$	0.219 ± 0.070
7	Total plant moisture content during harvesting, %	47.07 ± 3.88
8	Seed moisture content in the grain tank, %	17.94 ± 0.28
9	Seed cleanliness in the grain tank, %	95.54 ± 0.32

After pre-cleaning of the seeds using sieves and the air flow white mustard still contained 1.32 ± 0.33 % of seeds of hard-to-clean weeds – field mustard and rambling smartweed – which have similar physical and aerodynamic characteristics to the white mustard seed.

Special seed cleaning-sorting of white mustard seeds was performed using an experimental stationary stand based on the rigidity of dry seeds, when they freely fell from the heights of 0.5; 1.0; 1.5 and 2.0 m on the surface of a wooden and metal plate with the inclination angle to horizon of 25º; 30º and 40º. The fundamental indicator of sorting – distribution of mustard and weed seeds into fractions (%) depending on the aforementioned variable parameters and seed displacement (final result) with respect to the horizontal axis in the range of 0-1.40 m (7 fractions-containers of 0.20 m in width). All the versions of trials performed showed that Fractions 1 and 2 of the sorted white mustard contained most of weeds, field mustard and rambling smartweed (Table 4), and white mustard seeds of the lowest density. The findings showed that it is beside the purpose to use seeds of these two groups for production of superior quality sowing material; accordingly they were not included in Table 2 (those two fractions can be used as seeds only in case the grown and matured white mustard is to be ploughed-in for the purpose of soil fertilisation or used for production of oil). All the seven fractions were filled by white mustard seeds only when falling from the height of 2.0 m. Falling from the height of 1.5 m seeds filled in only six fractions, and from 0.5 and 1.0 m – seeds filled only fractions 1-4 in all the versions of the trials performed, leaving the troughs of fractions 5-7 empty. Consequently, these two rather low heights were excluded from further research. Table 2 shows total results of seed weight distribution among 3-7 fractions. The seed mass was supplied to the inclined plane with wooden and metallic surface at the feed rate of 1.57 ± 0.08 kg·min^{-1}. The seeds were falling from the height of 1.5 and 2.0 m.

The total results of white mustard seed distribution presented in Table 2 show that superior results were achieved in all the trials when the seeds fell freely from the height of 2.0 m. Falling from the height of 1.5 m on the wooden plate resulted in 20-42 % lower total seed weight of fractions 3-7 when compared to the trial with the seeds falling from the height of 2.0 m. Feeding seeds to the metal plate resulted in this comparative indicator to be respectively by 12-25 % lower. Assessment of the inclination angles of both types of plates with respect to the total weights of seed fractions reveals that superior results were obtained at the inclination angle to horizon of 25 and 30 degrees. At the inclination angle of 40 degrees, the seed fractions contained approx. 40 % less seeds when the inclined plane was made of wood. In case of the metallic inclined plane, the fractions contained by approx. 23 % less seeds (when compared to the results at the inclination angles of 25 and 30 degrees).

Table 2

Total results of sorting white mustard seeds into fractions 3-7 (in %)

Seed fractions	Proportions of seeds in fractions (%), material of the inclined plane, angle of inclination to horizon α (º) and height from which seeds were released h (m)											
	wood						metal					
	25º		30º		40º		25º		30º		40º	
	height from which seeds were released h, m						height from which seeds were released h, m					
	1.5	2.0	1.5	2.0	1.5	2.0	1.5	2.0	1.5	2.0	1.5	2.0
3	19.6	23.4	23.0	21.3	15.8	17.1	18.9	18.8	20.2	19.4	19.7	17.8
4	6.86	19.0	8.93	20.0	4.62	7.81	13.7	19.1	15.2	19.6	10.4	14.8
5	0.80	3.46	1.07	4.70	1.21	1.57	3.53	8.18	3.20	7.07	2.53	3.60
6	0.22	0.82	0.46	1.05	0.75	1.02	0.91	2.53	0.81	2.27	0.67	1.20
7	–	0.32	–	0.21	–	0.54	–	0.68	–	0.80	–	0.40
Total:	27.5	47.1	33.5	47.3	22.5	28.0	37.1	49.4	39.5	49.2	33.3	37.9

In summary of the research findings, the optimal option of all the investigated versions of white mustard seed sorting into fractions based on their rigidity is the one when the seeds are released to fall freely from the height of 2.0 m on the metal plate at the inclination angle of 30 degrees.

Fig. 2 shows the weight distribution for white mustard seed sorting into fractions depending on the seed feed rate q to the inclined plane. This relation shows that the higher feed rate of seeds supplied to the inclined plane, the lower amount of them fall into fractions 3-7. The reason behind this is that seeds bouncing from the inclined plane start hindering each other to get into more distant troughs (because the trajectory of the seed flight to troughs is altered as it shortens).

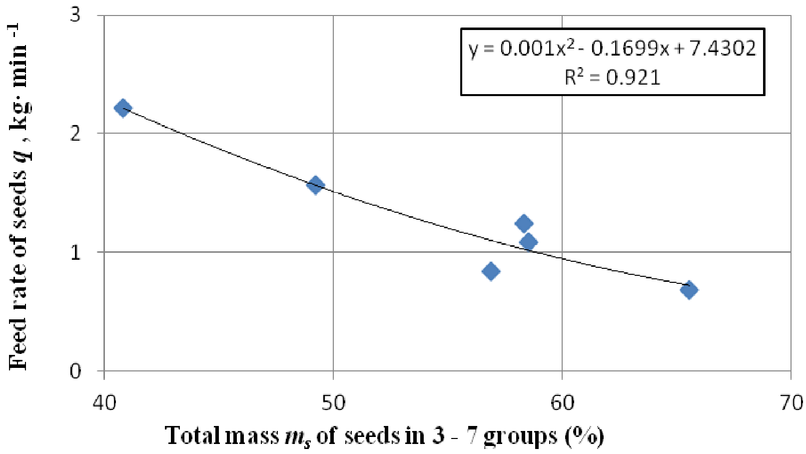

Fig. 2. **Dependency of distribution of white mustard seeds into fractions 3-7 on feed rate of seeds *q* to inclined plane**

Table 3 was developed with the aim to find an optimal feed rate *q*. The lowest total amount of seeds in fractions 3-7 (40.80 % of total seed weight) under the seed feed rate $q = 2.22$ kg·min^{-1} was considered equal to 100 %. The table also presents variations in the calculated total amount of seeds. At the feed rates of 1.09 and 1.24 kg·min^{-1} the aforementioned variation was respectively by 43.5 % and 43.0 % higher. The feed rate *q* of 1.24 kg·min^{-1} of white mustard seeds to the inclined plane was considered to be optimal.

Table 3

Total results (%) of mass distribution when sorting white mustard seeds into fractions 3-7 depending on feed rate of seeds *q* onto the inclined plane

Seed fractions	Feed rate of seeds *q* for sorting, kg·min^{-1}				
	0.687	**1.24**	**2.22**	**0.836**	**1.09**
3	21.68	19.45	15.56	18.75	19.77
4	25.70	21.54	13.77	22.30	22.07
5	13.12	11.63	7.26	11.21	11.53
6	3.82	4.30	3.16	3.48	3.99
7	1.23	1.42	1.05	1.13	1.17
Total (%):	65.55	58.34	40.80	56.87	58.53
± % of min.	+ 60.7	+ 43.0	100 %	+ 39.4	+ 43.5

Fig. 3 shows variation in total mass m_s of 1000 sorted white mustard seeds depending on their fraction number in optimal case. The conditions of the seeds sorting into fractions were as follows: the height from which the seeds were released – 2 m, surface of the inclined plane – metal, plane inclination angle to horizon – 30 degrees, feed rate of the seeds supplied to the inclined plane – 1.24 kg·min^{-1} of white mustard seeds. Control: the weight of non-sorted 1000 seeds m_s amounted for 7.79 ± 0.21 g. The diagram shows that more distant fractions (starting with the Fraction 3) have this indicator increased by approx. 0.5 g. Figure 4 shows the dependency of the white mustard seed density ρ on the fraction number in the optimal case (of those under investigation). The conditions of the trial were the same as discussed above in case of Fig. 3, except the density ρ of non-sorted white mustard seeds amounted for 743.00 ± 14.26 kg·m^{-3}. The curve representing the dependency of the seed density on the fraction number shows that seeds of higher density bounce from the plane farther and tend to fall into the more distant fractions.

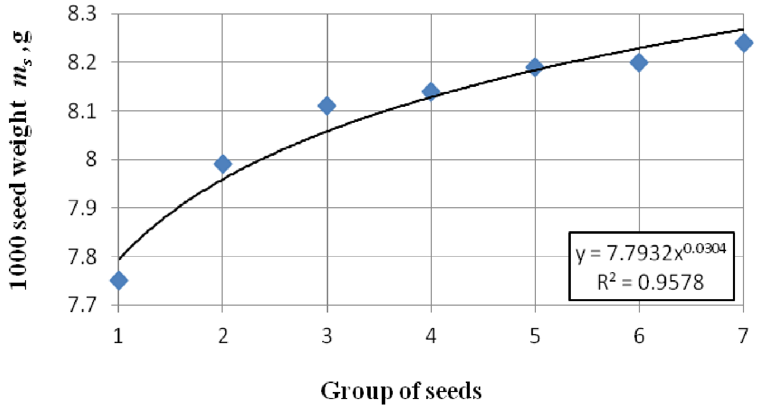

Fig. 3. **Dependency of 1000 sorted white mustard seeds on fraction number**

When harvesting ecologically grown white mustard (*Sinapis alba*) seed yield, a high amount of unwanted weed seed types fall into the grain tank of a combine harvester together with the threshed seeds of the cultivated plants. Most weed seed types can be separated by initial machine cleaning by the help of sieves and the air flow. However, such separation is not possible without a significant loss of cultivated crop seeds with two types of weed seed – field mustard (*Sinapis arvensis*) and rambling smartweed (*Polygonum convolvulus*), which have similar physical and aerodynamic characteristics to the white mustard.

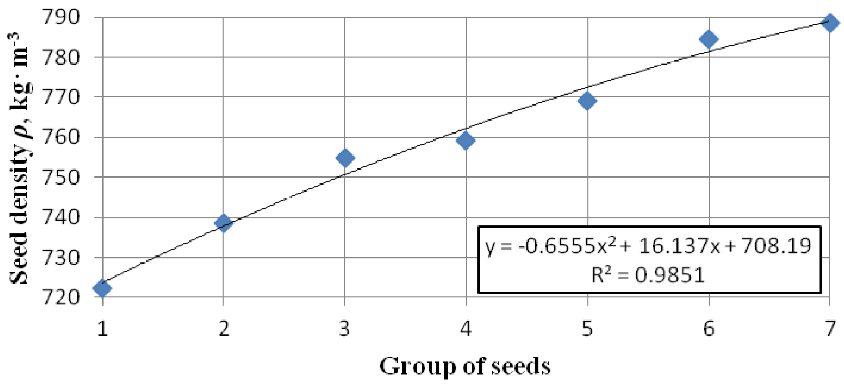

Fig. 4. **Dependency of white mustard seed density on fraction number**

When sorting seeds based on their rigidity by the help of an experimental stationary stand the proportion of hard-to-clean field mustard seeds was decreased by 25-40 % when compared to the control, whereas the proportion of rambling smartweed seeds was reduced twice in Fraction 3, and in Fraction 4 and onwards it was equal to zero (Table 4), i.e. the seeds were fully cleaned.

Table 4

Proportion of weed seeds (%) in fractions of sorted white mustard seeds

Seed fractions	**Proportion of weed seeds, %**		
	Field Mustard	**Rambling Smartweed**	**Totals**
1	0.92 ± 0.09	0.73 ± 0.28	1.65 ± 0.30
2	0.93 ± 0.07	0.71 ± 0.14	1.64 ± 0.23
3	0.85 ± 0.30	0.23 ± 0.23	1.08 ± 0.10
4	0.70 ± 0.24	0	0.70 ± 0.24
5	0.77 ± 0.12	0	0.77 ± 0.12
6	0.69 ± 0.16	0	0.69 ± 0.16
7	0.54 ± 0.17	0	0.54 ± 0.17
Control	0.93 ± 0.30	0.39 ± 0.14	1.32 ± 0.33

Table 5

Quality parameters of white mustard seeds sorted into fractions based on their rigidity

Seed fractions	Quality parameters of seeds and their measurement units			
	Weight of 1000 seeds, g	Density, kg m^{-3}	Seed germination energy, %	Seed germination power, %
1	7.75 ± 0.35	722.33 ± 22.26	79.00 ± 4.11	79.50 ± 3.05
2	7.99 ± 0.38	738.69 ± 4.48	83.50 ± 5.44	84.50 ± 4.00
3	8.11 ± 0.22	754.94 ± 22.56	85.00 ± 5.51	88.00 ± 2.60
4	8.14 ± 0.16	759.36 ± 17.07	91.00 ± 7.58	94.00 ± 2.60
5	8.19 ± 0.26	769.05 ± 20.47	93.00 ± 4.11	94.00 ± 2.60
6	8.20 ± 0.22	784.53 ± 13.77	93.50 ± 3.05	94.50 ± 3.05
7	8.24 ± 0.22	788.64 ± 9.24	94.00 ± 2.60	95.00 ± 4.11
Control	7.79 ± 0.21	743.00 ± 14.26	83.00 ± 5.72	85.00 ± 5.72

Table 5 presents the quality parameters of white mustard seeds sorted into fractions based on their rigidity. Seed germination energy and seed germination power, when compared to the control, did not decrease and starting with fraction 2 and onwards increased by approx. 10 % (in absolute values). White mustard seeds of fractions 1 and 2 are excluded from to the superior category of the sowing material due to their lower density, lower weight of 1000 seeds, lower seed germination power and higher proportions of contained weed seeds.

Conclusions

1. The moisture content of white mustard seed harvested by a combine-harvester amounted for 17.94 ± 0.28 %, and seed cleanliness in the grain tank of the combine-harvester – 95.54 ± 0.32 %. After pre-cleaning of the seeds using sieves and the air flow white mustard still contained 1.32 ± 0.33 % of seeds of hard-to-clean weeds – field mustard and rambling smartweed – which have similar physical and aerodynamic characteristics to the white mustard seed.
2. Special seed cleaning-sorting of white mustard seeds was performed using an experimental stationary stand based on the rigidity of dry seeds, when they were released to fall freely from the heights of 0.5; 1.0; 1.5 and 2.0 m on the surface of a wooden and metal plate with the inclination angle to horizon of 25º; 30º and 40º. The fundamental indicator of sorting – distribution of mustard and weed seeds into fractions (%) depending on the aforementioned variable parameters and seed displacement (final result) with respect to the horizontal axis in the range of 0-1.40 m (7 fractions-containers of 0.20 m in width). With increasing the number of fraction (seed displacement with respect to the horizontal axis), the weight of 1000 seeds m_s (g) and seed density ρ (kg m^{-3}) was found to increase, however part of higher density seeds (%) was found to decrease. With increase in the number of fraction, the proportion of weed seeds in fractions (when sorting based on seed rigidity) was decreasing.
3. The optimal option of all the investigated versions of white mustard seed special cleaning-sorting was the one when the seeds were released to fall freely from the height of 2.0 m onto the metal plate inclined at 30 degrees angle to horizon at the average feed rate of 1.24 kg·min^{-1} (74.4 kg·h^{-1}) or 1.488 t (h·m)$^{-1}$ (length of the gap of the grain tank – 5 cm). In this case, the proportion of hard-to-clean field mustard seeds is decreased by 25-40 % when compared to the control, whereas the proportion of rambling smartweed seeds is reduced twice in Fraction 3, and in Fraction 4 and onwards it was equal to zero, i.e. the seeds were fully cleaned.
4. The white mustard seeds of fractions 1 and 2 are excluded from to the highest category of the sowing material due to their lower density, lower weight of 1000 seeds, lower seed germination power and higher proportions of contained weed seeds. Seed germination energy D_e (%) and seed germination power D (%), when compared to the control, did not decrease and starting with fraction 2 and onwards increased by approx. 10 % (in absolute values).

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