OVERVIEW OF SESAME RESEARCH IN BULGARIA

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Abstract: Mechanized harvesting of sesame is not solved problem in many places in the world because of significant losses of seeds. The essence of the problem consists in the fact that sesame capsules release seeds due to a slight mechanical impact or by the wind when ripening. For solving the problem in Bulgaria the sesame research is conducted in two directions. The first is selection sesame varieties, suitable for mechanized harvesting and the second is adaptation of existing equipment and development of new for harvesting sesame seeds. In 2015 has been developed a method for assessment the susceptibility of sesame genotypes for mechanized harvesting of the seed. The method is based on an impact of a pendulum and on calculation of three indices. The first index is a criterion for self releasing of seeds from capsules, the second index is a criterion for retention seeds in capsules and the third index - for strength of the link between seeds and placenta. The method was applied to assess the susceptibility of sesame varieties for mechanized harvesting as well as to choose parental pairs in the selection of new sesame genotypes. A lot of new sesame genotypes have been selected and they have higher indices then existing. Representative studies for mechanized harvesting the seed have been done through five different technologies and machines in Bulgaria. The best results are shown by the two new developed devices. The first is for feeding sesame stems into harvesting machine. It squanders 3.4 times less sesame seeds than the grain harvester Wintersteiger - Hege 160 at parallel harvesting of hybrid f3/361-6-3 at seed moisture content of 8.9%. The second is for inertial threshing of sesame seeds. It threshes over 95% of seeds of non-shattering varieties Aida and Nevena without reducing their germination at seed moisture content from 12.2 to 13.3% while the conventional thresher decreases germination with 27%. The productivity of the conventional thresher is 1.4 times higher than that of the inertial thresher. The total power consumed by the inertial thresher is 4.81 times smaller than by the conventional thresher, because it does not deform stems and capsules during operation.

Keywords: SESAME, MECHANIZED HARVESTING, METHOD OF ASSESSMENT, BREEDING

1. Introduction

The sesame (Sesamum indicum L) is known as the oldest oil crop in Bulgaria. The seeds are used as raw material for preparation of oil, food, cosmetics and medicines. Now the country has shortage of sesame seeds and annually imports from China, India, Ethiopia, Sudan and other countries. In the past the sesame fields occupied 3% of agricultural land in Bulgaria but now they are 0.06%. The main reason for this negative statistic is the significant loss of seed at mechanized harvesting, which is a problem worldwide.

For solving the problem in Bulgaria is conducted sesame research in two directions:
- Selection sesame varieties, suitable for mechanized harvesting. Research is done at Institute of Plant and Genetic Resources - Sadovo since 50 years.
- Adaptation of existing equipment and development of new for harvesting sesame. This direction of research is conducted at Agricultural University - Plovdiv from 15 years.

The aim of the paper is review the results of sesame research in Bulgaria in recent years.

2. Results from selection and breeding of sesame varieties, suitable for mechanized harvesting

1. Results of selection and breeding of sesame varieties

1.1. Origin of Bulgarian sesame varieties

In the beginning, Bulgarian sesame researchers thought that an effective mechanized harvesting of seeds is possible only for varieties whose do not shatter the capsules at ripening (Georgiev, 2000; Georgiev, 2002; Georgiev et al., 2008). For that purpose in 1989 at the Institute of Plant Genetic Resources - Sadovo was imported a non-shattering sesame sample № 87010 from the Institute for Oilseeds in Krasnodar, Russia. It has been included in hybridization with Bulgarian breeding lines in order to create new sesame generation, suitable for mechanized harvesting with grain harvesters. The first hybrid materials were with the following adverse signs:
- Deformed thick stems;
- Semi-upright central stem with low-lying capsules and sloping side branches;
- Thickened of central stem with strong shortened internodes in the top part of the plant and accumulation of large number of small capsules;
- Abnormal number and underdeveloped side branches located on the top of plants;
- Leaves with strongly altered form, similar to those damaged by herbicides;
- Large flowers with extra appendages as parts of petals;
- The top of the plants ends with 4 - 5 short branches with a minimum number of capsules;
- Large percentage of aborted capsules;
- Strong susceptibility to diseases.

Many of these undesirable traits were removed after multiple selection, reciprocal crosses and inclusion of new breeding sesame lines (Georgiev et al., 2014). They have low yield and long drying period on field and for this reason was recommended usage of defoliants (Stamatov, 2010). In spite of all, from 25% to 50% of capsules did not allow threshing and mechanically damaged seeds reached 50% (Ishpekov et al., 2008; Ishpekov et al., 2012; Ishpekov et al., 2014). As a result was created the first Bulgarian non-shattering variety named Victoria.

1.2. Approaches in breeding of new varieties

Bulgarian hybridization program started in 2006 and in the beginning has not been paid due importance to selection of parental pairs. As straight and reciprocal crosses were included varieties with shattering and non-shattering capsules. For parents were selected breeding lines with non-shattering capsules and without side seam. The selection of breeding lines and varieties with shattering capsules was carried out only according with potential for high yield. The assessment of obtained progeny also was not sufficiently substantiated. The selection approach has been changed after identification of the attached placenta in capsules of Aida variety in 2011. The selection of parents has already based on the suitability for mechanized harvesting combined with high yield (Georgiev et al., 2011; 2012; Stamatov and Deshev, 2010; 2012). The breeders discovered that the hybridization of non-shattering genotypes without side seams leads to unsatisfactory results. It was found that the desired features in terms of the architecture of capsules occur in the progeny F2. The selection of newly established materials was carried out by signs responsible primarily for the architecture of capsules. By subjective assessment was sought:
- Capsules with a small hole at the top;
- Capsules, whose side seam ends to the middle of its length;
- The membranes that are securely attached for placenta;
- Capsules that are narrowed on the top.

1. Overview of sesame research in Bulgaria

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Seeds that are firmly attached to the placenta and plant tilting do not lead to releasing of seeds at maturation. The suitability of sesame varieties for mechanized harvesting was assessing in real field conditions through determining the qualitative indices of grain harvesters. This requires a large sesame field, a large team of staff and researchers, expensive grain harvester in busy period and big consumption of time. The main conclusion was that this approach slows the selection process therefore the sesame breeder needs of method for assessing the susceptibility of varieties for mechanized harvesting of seed in early stage of the selection.

1.3. Bulgarian method for evaluating the susceptibility of sesame varieties to mechanized harvesting

In 2014 has been developed a subjective independent method for assessment the susceptibility of sesame genotypes for mechanized harvesting of seeds by Ishpekov and Stamatov (2015b). It purpose is evaluating effects of placenta attachment, of membranes and of capsule shape on percentage of released seeds through objective criteria (Ishpekov et al., 2015a). The method includes preparing of materials, seed retention test and capsule crash test and requires 100 capsules of each variety - one week before opening their tips. Capsules are cut off from the middle zone of stems of different plants. Such amount of capsules is necessary for assessment genotypes at three values for moisture content of seeds. Capsules are cut while they are completely closed and are packed in paper bags by fours. The bags have been left in the laboratory until the opening the tips of capsules, which is a sign for starting of experiment.

The method is conducted through an experimental system which consists of a pendulum apparatus and an electronic system for measuring and recording the angle of rotation of the pendulum (Fig. 1).

The apparatus consists of base 1 on which is mounted a support 2 and a pendulum bar 3 with the plate 4. The scale 14, with trigger for measuring and recording the angle of rotation of the pendulum which consists of a pendulum apparatus and an electronic system for assessment the susceptibility of sesame genotypes for mechanized harvesting of seed in early stage of the selection.

![Fig. 1 Experimental system for investigation releasing of sesame seeds from capsules](image1)

The seed retention test begins after sticking four sesame capsules 5 on the plate 4 when the pendulum is at equilibrium position (Fig. 2). The electronic system is started and the pendulum with the examined capsules is deviated and locked at the assigned angle through the scale 14. After a second the pendulum is released by the trigger 15 and it is hit to the anvil 6, which does not contact with capsules. The pendulum shaft 13 rotates the encoder's rotor 11 through the clutch 12. The signal is read by an electronic counter USB-1208HS-2AO and is delivered to computer - 8 via USB. The signal is displayed through virtual instrument, which had been developed in the environment of LabView (www.ni.com/labview), (Fig. 3).

![Fig. 2 Pendulum apparatus with capsules](image2)

![Fig. 3 Graph of the signal from experimental system](image3)

**Graph of the signal from experimental system**

Point A - the pendulum is contacted with the anvil in the equilibrium position; B - the pendulum is diverted on 29 degrees; C - impact of the pendulum into the anvil; D - the maximum deviation of the pendulum after the collision; U₀ - indication of the measurement system before the release of the pendulum; U₁ - indication of the measurement system at the pendulum rebound; Δt - the duration of the impact.

Due to the impact, each seed in capsules has loaded with the following inertial force

$$ F_v = m_v a_v , $$  \hspace{1cm} (1) $$

where:

$ m_v $ - the average mass of a sesame seed, kg;

$ a_v $ - the acceleration, which was given to the seed, $ m/s^2 $. In this case, it is calculated as follows

$$ a_v = \frac{\dot{v} - \dot{v}_0}{\Delta t} , $$  \hspace{1cm} (2) $$

where:

$ v_0 $ - is the capsule velocity just before impact, $ m/s $$;  
$ \dot{v}_0 $ - the duration of impact, $ s/10^{-3} $. The impact duration is read from the signal of measuring system.

The plate velocity before impact is calculated as follows

$$ v_0 = \dot{\theta}_b l_b , $$  \hspace{1cm} (3) $$

where:

$ l_b $ - is the length of pendulum bar 3, $ m $;

$ \dot{\theta}_b $ - the angular velocity of pendulum before impact, $ s^{-1} $. It is determined as a function of the work done by the pendulum at falling from angle $ \alpha $ -

$$ \dot{\theta}_b = \frac{\dot{\theta}_p (m + m_p) (v_0 + 2 m p)}{2 R_p m_p R s m m_p} (m + m_p) + \frac{1}{l_b} \left( m_p + m_0 \right) $$  \hspace{1cm} (4) $$
where:
\( \zeta \) is the coefficient for accounting the friction losses in the bearings of pendulum and of incremental encoder;
\( g \) - the gravity acceleration, \( m \, s^{-2} \);
\( m_0 \) - the mass of pendulum bar, kg;
\( m_p \) - the mass of plate with tested capsules, kg;
\( R_i \) - the radius of clutch, m;
\( m_{cl} \) - the mass of clutch, kg;
\( R_{cl} \) - the radius of encoder’s rotor, m;
\( m_{enc} \) - the mass of encoder’s rotor, kg.

The seeds leave capsules due to the inertial force and are impossible to collect them. Their quantity is determined indirectly by weighting of:
\( m_{0} \) - the mass of tested capsules before test, g;
\( m_{1} \) - the total mass of seeds, which fall down as a result of slow rotation of the capsules with the tip down, g;
\( m_{2} \) - the mass of glue, g;
\( m_{j} \) - the mass of capsules after impact, g;
\( m_{3} \) - the mass of seeds, retain in capsules after impact, g;
\( m_{4} \) - the total mass of tested capsules and of glue, g.

The mass of the seeds leaving capsules due to inertial force is:
\[ m_{3} = m_{2} - m_{3} \]

Three indices have been introduced:
\[ i_{1} = \frac{m_{3}}{m_{1}} \]  
\[ i_{2} = \frac{m_{1}}{m_{3}} \]  
\[ i_{3} = \frac{m_{3}}{m_{2}} \]  

The first index \( i_{1} \) is a criterion for self releasing of seeds by the capsules. The second index \( i_{2} \) is a criterion for retention seeds in capsules. The third index \( i_{3} \) is a criterion for the strength of link between seeds and placenta. The varieties with high values of the index \( i_{3} \) are unsuitable to mechanical harvesting due to self release of seeds. The varieties with high values of index \( i_{2} \) allow threshing of seeds after breaking capsules only. The high value of index \( i_{3} \) is indicative of suitability for harvesting seeds without breaking of capsules namely by conventional threshing. The results of application seed retention test are shown in Figures 4 and 5.

The second test is for crashing of capsules and begins after sticking a capsule on front side of the anvil (Fig. 2). It allows studying the shock and shattering resistance of the capsules that remain closed at maturation (Ishpekov et al., 2008). The appropriate shock impulse for releasing seeds from closed capsules is in the range from 45 to 0.65 kg m s\(^{-1}\) and is given by a striker with 5 mm width. This test is applied for genotypes with high index \( i_{1} \) and low \( i_{2} \). The genotypes 240, 460, 463, 464, 465 and 504 were subjected to this test at seed moisture from 6.6 to 7.2%. The results show that the highest percentage of seeds is released by the shock impulse in the range \(- S = 0.35 - 0.40 \, \text{kg m} \, \text{s}^{-1} \) (Fig. 6). On shock impulse over 0.45 kg m s\(^{-1}\), the percentage of released seeds decreases, because they left in capsules and are severely damaged (Figures 7 and 8). These genotypes are characterized with tightly adhering membrane and with narrowing the walls of capsules. On one hand, this prevents the release of seeds due to shaking of plants, but on the other hand it causes losses from bad threshing and from mechanical damage of seed.

The developed method can be used for the following purposes:
- To assess the susceptibility of sesame genotypes for mechanized feeding of stems and for threshing of capsules.
- To select the appropriate way of threshing, this can be with or without breaking the capsules.
- For choosing of parental pairs in the selection of new sesame genotypes, which are intended for mechanical harvesting.

- To synthesize the appropriate mechanical impacts for feeding of stems without seed loss and for threshing seeds without their mechanical damage. That is usually done at construction and adaptation of harvesters.
1.4. Indices of Bulgarian sesame varieties

The mentioned Bulgarian method has been applied for 3 years. The result is obtaining genotypes with indices $i_2$ and $i_3$, which are higher than those of varieties, selected before applying the method. From Table 1 is evident that the new hybrid F3/361-6-3 has index $i_2 = 3.694$, which value is 8.2 times higher than that of the Aida variety and the hybrid F2/365-28 has index $i_2 = 3.423$, which value is 10.1 times higher than that of the Nevena variety.

The results obtained show not only the varieties that are suitable for mechanized harvesting of seeds but also the appropriate ways for their threshing. More over, genotypes with high values of $i_2$ produce low seed yield and those with high values of $i_3$ are high-yielding. This assessment enables the selection of parental pairs and offsprings selection. The negative relationship between yield and high index $i_2$ and the positive between high index $i_3$ and yield allows selecting high-yielding sesame forms suitable for mechanized harvesting (Stamatov et al., 2017).

Table 1 Progeny of different sesame generations

<table>
<thead>
<tr>
<th>№</th>
<th>Progeny</th>
<th>Mass of seeds in a plant, g</th>
<th>Mass of seeds in a capsule, g</th>
<th>$i_1$</th>
<th>$i_2$</th>
<th>$i_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varieties, selected before applying the method and tested in 2014</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Aida</td>
<td>12.7</td>
<td>0.087</td>
<td>1.19</td>
<td>0.18</td>
<td>0.45</td>
</tr>
<tr>
<td>2</td>
<td>Nevena</td>
<td>13.5</td>
<td>0.081</td>
<td>1.50</td>
<td>0.34</td>
<td>0.37</td>
</tr>
<tr>
<td>3</td>
<td>Valia</td>
<td>16.6</td>
<td>0.098</td>
<td>4.81</td>
<td>0.18</td>
<td>0.02</td>
</tr>
<tr>
<td>Genotypes, selected after applying the method and tested in 2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>f3/361-7-3-1</td>
<td>3.52</td>
<td>0.085</td>
<td>3.87</td>
<td>0.58</td>
<td>2.64</td>
</tr>
<tr>
<td>2</td>
<td>f2/364-15</td>
<td>12.8</td>
<td>0.082</td>
<td>0.31</td>
<td>0.33</td>
<td>3.40</td>
</tr>
<tr>
<td>3</td>
<td>f3/361-6-1</td>
<td>10.2</td>
<td>0.188</td>
<td>0.97</td>
<td>0.38</td>
<td>2.18</td>
</tr>
<tr>
<td>4</td>
<td>f2/364-18</td>
<td>3.18</td>
<td>0.225</td>
<td>1.21</td>
<td>1.49</td>
<td>1.39</td>
</tr>
<tr>
<td>5</td>
<td>f3/361-7-8-1</td>
<td>16.0</td>
<td>0.200</td>
<td>7.02</td>
<td>0.03</td>
<td>2.77</td>
</tr>
<tr>
<td>6</td>
<td>f4/355-2-1</td>
<td>9.8</td>
<td>0.250</td>
<td>1.56</td>
<td>1.56</td>
<td>2.76</td>
</tr>
<tr>
<td>7</td>
<td>f2/364-20</td>
<td>15.2</td>
<td>0.187</td>
<td>4.44</td>
<td>0.40</td>
<td>0.47</td>
</tr>
<tr>
<td>8</td>
<td>f3/361-6-3</td>
<td>14.7</td>
<td>0.182</td>
<td>0.84</td>
<td>2.56</td>
<td>3.69</td>
</tr>
<tr>
<td>9</td>
<td>f2/365-27</td>
<td>15.0</td>
<td>0.250</td>
<td>3.15</td>
<td>0.60</td>
<td>0.66</td>
</tr>
<tr>
<td>10</td>
<td>f2/365-28</td>
<td>4.3</td>
<td>0.055</td>
<td>0.39</td>
<td>3.42</td>
<td>3.10</td>
</tr>
</tbody>
</table>

2. Results of mechanized harvesting of sesame seed

Most of field operations for sesame growing allow conducting by conventional mechanization in this figure tillage, sowing, plant protection and irrigation. But most of fields are harvested manually worldwide. Small percentage of sesame fields is harvested by grain harvesters with significant losses of seeds.

In the recent years many sesame varieties assigned for mechanized harvesting have been selected in Bulgaria. According type of capsule at maturation they are of two groups:
- Variety Viktoria which has closed capsules.
- Varieties Nevena, Valia, Aida, that open the tip of capsules, but the seeds remain attached to placenta.

From 2010 to 2018 many representative studies for mechanized harvesting the seed of both types of varieties have been done by five different technologies and machines.

First technology: One-phase harvesting with grain harvester;
Second technology: Two-phase stem harvesting and threshing:
- First phase: Cutting and draying of stems;
- Second phase: Stems threshing.

Third technology: Two-phase capsules harvesting and threshing:
- First phase: Collecting capsules from plants, while they are on root;
- Second phase: Draining and threshing capsules.

Fourth technology: One-phase harvesting of seeds with knocking machine;

Fifth technology: One-phase harvesting of seeds through two new devices developed at Agricultural University – Plovdiv. First device is for feeding sesame stems into harvesting machine and second is an inertial thresher.

2.1. Results from the first technology

The representative study the indices of grain harvester require its adaptation and namely manufacturing and installing of a few tools (Trifonov et al., 2013):
- A tool for collecting samples from harvested seeds (Fig. 9).
- Two self unscrew canvases for collecting samples from the cleaner and from the straw walker (Fig. 10).

The following main indices were obtained during harvesting varieties Viktoria and Nevena at moisture content of seeds between 8 to 14.8%:
- Losses by the header 17 - 22%.
- Losses by the threshner 2 - 3%.
- Mechanically damaged seeds by the thresher 23 - 50%.
- Germination of harvested seeds 40 – 56%.

The main conclusion is that the losses by the header grow when the moisture content of seeds is under 10 % and the losses by the threshner grow when the moisture content of seeds is over 10 %.

2.2. Results from the second technology

In the first phase green stems are cut by conventional cutter bar and after that they are dried on field. In the second phase the dried stems are threshed by MSSZK which has been developed at Rousse University (Fig. 11). The main differences of the MASZK from conventional thresher are in two sets of drums, which work consecutively. The first set includes two aluminum crushing drums, and the second - a rubbery threshing drum.

The following indicators were obtained at threshing Viktoria variety which has closed capsules at full maturity and moisture content of seeds 61%:
- The portion of threshed seeds 91.07%.
- Seed germination 65 - 85%.
- Small productivity;
- High energy consumption;
- Requirement for thin sesame stems;
- Suitable for breeding.
2.3. Results from the third technology

It is characterized with two-phase harvesting and threshing of capsules. During the first phase the capsules are harvested from the plants, while they are on root by an experimental finger device, developed at Agricultural university of Plovdiv (Fig. 12). After drying down the harvested capsules are threshed by MSSZK (Figure 11). The main results obtained at harvesting capsules of Viktoria variety with 8.7 % moisture content of seeds are:

- The percentage of harvested capsules is 87.8 %;
- The impact of the fingers is from down to up and is applied to the bottom of capsules. It causes releasing of seeds from majority of capsules.

2.4. Results from the fourth technology

It is one-phase harvesting of seeds by an experimental knocking machine, developed at Agricultural University – Plovdiv (Fig. 13). A parallel study for harvesting Aida variety by hand and by the mentioned machine was conducted in 2013. At moisture content of 11.4% the percentage of harvested seed are:

- At one-way manual harvesting - 69.1%;
- At one-way harvesting by knocking machine - 73.4%.

The rest of seeds are the total losses from harvesting.

2.5. Results from the fifth technology

This technology is new and is not fully completed. The harvesting of sesame seeds is in one phase and is conducted by two new experimental devices, developed at Agricultural University - Plovdiv. The first device is for feeding sesame stems into harvesting machine which structure is shown in Fig. 14. The specific for the new finger device is:

- The plants are caught laterally not from the top like by the combine reel;
- The cutting of stems is after tilting over the combine platform.
- The feeding of stems into harvester is without any shocks and vibrations of plants.
- The position of the collecting surfaces is changeable for stems with different habitus.
The device allows adjusting the angle of stems toward platform at moment of their cutting from roots.

**Fig. 14** Scheme of the finger device for feeding sesame stems into harvesting machine (Patent pended)


The main results obtained by the new finger device at feeding stems of Aida variety with 9.7 % moisture content of seeds are:

- It achieves the minimum percentage of seed loses of 2.5% in working mode with kinematic coefficient 1.33 and forward speed of 0.83 m s\(^{-1}\).

- The increasing of forward speed from 0.63 to 1.33 m s\(^{-1}\) leads to growing up of both the device productivity from 1.59 to 3.35 ha h\(^{-1}\) for each harvested row and the seed losses up to 5.25%, although the kinematic coefficient remains constant.

A parallel study was conducted with the hybrid F3/361-6-3 at seed moisture content of 8.9% with the aim to determine the seed losses by the new device and by the Wintersteiger - Hege 160 grain harvester (Figures 15 and 16). Both machines move with the forward speed \(v_M = 1.33\) m s\(^{-1}\) as well as the kinematic coefficients of the harvester reel and of the device feeding chains were equal to 1.33. Under these conditions, the new device squanders 8.8% from the yield and the Hege 160 harvester - 30.2%, which is a difference of 3.4 times. The new feeding device is designed for harvesting one row, but it can be used as a base for building multi - rows header for each grain harvester.

Significantly higher losses by the combine harvester are rooted in inappropriate impact of the reel and of the cutting apparatus on sesame plants (Langham, 2014; Naydenov et al., 2016). The reel wedges between central stem and capsules or branches as a result of which it bends the stems to soil surface. The cutter bar shakes stems several times before cutting them off the root. This causes releasing of seeds, detaining over the bar and after accumulation - falling down on soil surface (Fig. 16).

**Fig. 15** Seed losses

The second device is for inertial threshing of sesame seeds (Fig. 17). The main unit of the thresh is a rod spindle 5, which performs asymmetric angular vibrations. They are composed of consecutive spins in two directions - toward the entrance and toward the exit of the thresh. The angular amplitude toward the exit is larger than amplitude toward the entrance. It is due to the action of the one-way clutch 3 and spring 4, which reduce angular amplitude toward the entrance (Ishpekov S., et al., 2015b).
In operation the stems are fed over grill 8 manually and then fall between rods of the spindle 5. It gives angular vibrations and simultaneously moving them toward the exit of the thresher. Due to vibrations the seeds leave capsules and fall into the bag 7 and stems 9 leave the thresher without being deformed. In this case, the seeds detachment is mainly due to the inertial forces that are created and transmitted to stems and capsules through the rod spindle 5. Therefore, this kind of threshing of the seed is called inertial. It does not require the breaking of the capsules for detaching the seeds, which is a significant difference from the threshing in the grain harvesters.

The indices, obtained by the inertial thresher, by the conventional thresher and indices of manually threshing of sesame from one variety and equal moisture of the seeds have been compared. The developed device threshes over 95% of seeds from the non-shattering varieties Aida and Nevena without reducing their germination at seed moisture content from 12.2 to 13.3%, which is two times higher than recommended for harvesting sesame with grain harvester. The portion of the impurities in threshed mixture is from 20.99 to 38.41 percent depending on varieties (Fig. 18).

The conventional thresher decreases 27% germination of seeds with 13.3% moisture content due to mechanical damaging, which is also the main reason for development of seed diseases during storage (Fig. 19). The impurities in the threshed mixture are 56.5%, half of which does not allow separation by the conventional grain cleaner. The productivity toward 1 m working width of the conventional thresher is 1.4 times higher than of the inertial thresher and is due to the different principles of threshing in both mechanisms. The total power consumed by the inertial thresher is 4.81 times smaller than by the conventional thresher with the same productivity, because it does not deform stems and capsules at releasing seeds, while in classic thresher this is inevitable (Zaykov at al., 2017).

**Fig. 16** The cutting apparatus is another source of seed losses by the grain harvester

**Fig. 17** Inertial thresher (patented) 
1 - pulse Chalmers mechanism, 2 - electric motor, 3 - one-way clutch, 4 - spring, 5 - rod spindle, 6 - stretching screw, 7 - bag for threshed material, 8 - grill, 9 - sesame stems, 10 - cleaners, 11 - lid

**Fig. 18** Components from threshing stems in the bag of the inertial thresher

**Fig. 19** Sesame germs 25 days after threshing

**Conclusions**

Selection improvement of Bulgarian sesame forms shows progress in increasing the ability of new breeding materials to retain the seeds in capsules at maturation. As a consequence of proper approach when selecting the parents of hybrid offspring have increased the indexes $i_2$ and $i_3$ due to changed anatomical features of sesame capsules. The indices evidence that the new offspring are more susceptible for mechanical harvesting as well as for threshing without destroying capsules. Till now have been selected three sesame varieties suitable for mechanized harvesting, as well as a large number of breeding lines. They are high-yielding and showed good susceptibility to harvest by combine harvester and also by the new device for feeding sesame stems and by the inertial thresher.

Five different technologies and machines for mechanized harvesting of sesame seed have been developed and evaluated in Bulgaria from 2010 to 2018. The most perspective is the one-phase technology which performs by two successively operating new devices. The first is a device for feeding sesame stems into harvesting machine which catches the plants laterally not from the top like the combine reel. During a parallel study with the hybrid f3/361-6-3 at seed moisture content of 8.9% and forward speed $1.33 \text{ m s}^{-1}$ the new device squanders 8.8% of the yield and the Hege 160 harvester - 30.2% which is a difference of 3.4 times. The second device is an inertial thresher which threshes over 95% of seeds from the non-shattering varieties without reducing their germination at seed moisture content.
moisture content two times higher than recommended for harvesting sesame with grain harvesters. The conventional thresher decreases 27% germination of seeds with 13.3% moisture content. Its productivity is 1.4 times higher than of the inertial thresher and is due to the different principles of threshing in both mechanisms. The total power consumed by the inertial thresher is 4.81 times smaller than by the conventional thresher with the same productivity, because it does not deform stems and capsules at releasing seeds. Both developed device are suitable alternative for the cutter bar and the thresh- er of conventional grain harvesters especially for conditions with high humidity in maturation season. They can be used for manufacturing of new machine for harvesting sesame or to change the existing header and thresher.

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