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CREATION, CONFIRMATION AND USE OF THE “ATTACHED PLACENTA” SIGN IN SESAME

AUTOHRS ABSTRACT

Of dissertation for award of the scientific degree “Doctor of Science” Field of higher education 6. Agricultural sciences and veterinary medicine;
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This dissertation written on 170 pages, contains 54 tables, 32 figures, 18 pictures and list of the literature used from 151 sources from which 12 in Cyrillic and 139 Latin alphabet.

INTRODUCTION

Sesame is the oil plant of the ancient world. The qualities of its oil are unsurpassed and equal to olive and walnut. The plants are extremely unpretentious and are distinguished by a very strong drought resistance. Well known in Asian countries, it is gaining more and more popularity in the rest of the world. The health benefits of consuming sesame are many and this necessitates its increased demand. An obstacle to the larger production of the crop is its biology. Sesame seeds burst their capsules when ripe and the seeds fall to the field before being harvested. This fact necessitates the use of manual labor, which includes cutting the green plants, storing them on platforms and subsequently shaking out the seeds.

The present work covers a seventeen-year period and traces the path to the realization of a new trait in the sesame plant called "attached placenta". This decision was imposed over the years in the selection of sesame in search of opportunities to introduce mechanization in the culture. The "attached placenta" allows the seeds to be retained in the pods as the plants gradually mature and open their capsules. The "attached placenta" plays a crucial role in preserving the seeds as they enter the threshing mechanism. The methods and manner of surveying the collection of species, the selection of parental pairs, and the selection in the hybrid progeny are described. The mechanism of retention of the seeds by the placenta was traced. Genetic control of "attached placenta" established. The selection strategies for fixing and strengthening the trait in the hybrid offspring are justified. Bulgarian methods for establishing the strength of the "attached placenta" have been implemented.

The dissertation is a scientific and practical guide to the successful application of conventional selection methods. The work in it shows that this type of selection has not lost its merits and still achieves sustainable results.

1. ISSUE STATUS

The need for mechanized harvesting of sesame first arose in Venezuela in the 1940s. The then government decided to solve the food problem caused by the lack of vegetable fats by introducing sesame as an oilseed crop into the country's agriculture. The problem farmers face then is that when the sesame seeds ripen, they open their capsules and the seeds are scattered in the field. This requires the plants to be cut while they are still green, strung into bundles, further dried on platforms and shaken out on a cloth. All this is associated with an extremely high amount of manual labor, which makes the production of the product expensive and inefficient (Langham and Rodriguez, 1949; Weiss, 1971, 2000; Davila, 1977; Kang, 2001, Cagirgan, 2006).

Many authors are of the opinion that the anatomical features of the sesame capsules and especially the shape of the seed chamber can solve the problem of the mechanization of the culture (Anon, 1981; Langham, 2001, 2006, 2013c, 2014; Ashri, 2007; Georgiev et al. ., 2011; Stamatov and Deshev, 2014; Yeasmin, 2015). Langham and Rodriguez (1945) and Langham (1946) found a mutation with non-shattering capsules first in the variety Venezuela 52 and identified the gene responsible for this trait - a recessive allele (id). In their original form, the capsules were so rough and strong that they had to be opened with a hammer (Langham and Rodriguez, 1946). The line possessing this allele has been proposed for research by breeders worldwide. For the next 50 years, they made attempts to solve the problems.

Langham et al. (1956) reported that the insertion of a new type of placenta ("attached placenta") between each seed is very important for the retention of the seeds in the capsule. Years later, these conclusions of his became the basis for the development of indehiscent sesame lines.

Realizing of the "attached placenta" trait in 2011 in Bulgarian genotypes reveals new perspectives for the mechanized harvesting of sesame (Stamatov and Deshev, 2010; Deshev and Stamatov, 2017; Stamatov and Deshev, 2018). During the period, attempts were made to directly harvest these forms with a conventional grain harvester (Trifonov et al., 2013; Ishpekov et al., 2014). The authors make a techno-economic evaluation of the operation of the conventional grain harvester. Bulgarian engineers substantiate a prototype that threshes sesame plants, avoiding the disadvantages of the harvester (Ishpekov et al., 2016).

Breeders use modern selection techniques to increase the yield in the newly obtained lines (Georgiev et al., 2011; Georgiev et al., 2012; Georgiev et al., 2014; Stamatov and Deshev, 2014; Deshev, 2015).

The selection of parental pairs and the selection of the resulting progeny is of primary importance for the preservation and consolidation of the "attached placenta" sign. Selection work in this direction is greatly hampered by the impossibility of defining a morphological feature of the plant that is directly related to the ability of the genotypes to retain their seeds at maturity. This fact is of primary importance for selecting forms suitable for mechanized harvesting. Now the authors have to use direct and indirect indicators related to the anatomical features of the capsule (Stamatov et al., 2020).

Since the trait "attached placenta" is negatively related to seed yield in sesame, it is necessary to seek a compromise in the selection-improving work with the culture (Ashri, 1998; Diouf et al., 2010; Georgiev et al., 2014). In the breeding-improvement work with sesame to select the most suitable parent pairs, a lot is relied on mathematical skills.

There is still no general model to work with, both with the plant material and with the statistical methods used.

2. WORKING HYPOTHESIS

The implementation of an "attached placenta" to hold the seed in the capsules until it enters the threshing mechanism is the way to solve the problem of mechanized harvesting of sesame. The production of “attached placenta” in sesame genotypes requires finding suitable parental pairs. Its manifestation in the progeny should be followed, as well as its correlation with the other mechanisms of seed retention (degree of capsule splitting, narrowing of the walls and the presence of an attached membrane) should be evaluated.

It is of paramount importance to evaluate the relationship of the trait with the architecture and productive qualities of the plants. Finding methods to assess the strength of the bond between it and the seed is critical to any successful breeding program.

Structured in this way, the work plan will allow full use of the trait in the breeding-improving work with the culture regarding the selection of forms suitable for mechanized harvesting.

The stated working hypothesis can be implemented by performing the following tasks:

1. Evaluation of the source gene-plasm;
2. Scientifically based selection of parental couples;
3. After the discovery of the sign "attached placenta", it is necessary to focus the work on the selection of parental pairs to fix the sign and strengthen its manifestation through selection in the hybrid progeny;
4. Verification of the genetic control of the trait;
5. Application of methods for evaluating the "attached placenta" sign;
6. Study of the relationship of the sign with other anatomical features of the fruit capsules, responsible for the retention of the seeds;
7. Creation of a core collection;
8. Comparison of methods for evaluation of sesame capsules.

3. MATERIAL AND METHODS

3. 1. Plant material

During the period 2004 - 2008, an agrobiological study was carried out on 22 Bulgarian breeding lines of sesame with non-shattering capsules, created in IRGR - Sadovo.

When conducting experiments to compare the morphological differences, biological properties and economic qualities of the lines withshattering and non-shatterig capsules, the sesame varieties - Sadovo 1 and Milena - were used as standards.

For the selection of parent pairs in order to detect the sign "attached placenta" in the progeny and improve the yield potential of the plants, in 2008 - 2009, lines with non-shattering capsules were included in the study. They are with selection numbers: 3850, 3962, 3958-1, 3959-2, 3859, 4071, 4073, 4074, 4075, 4050, 4053, 3959, 3959-3, 4069, 4047, 4051, 4055, 4056 and, 406 4068. Varieties with shattering capsules - Sadovo 1, Milena and Sofia - are also included for comparison.

To test the yield potential and the possibilities for mechanized harvesting of the obtained hybrid progeny in the period 2011 - 2013, 14 progeny selected according to subjective criteria were sown in a variety experiment, possessing the sign "attached placenta" . The most promising three of them participated in the research to establish the mechanism of retention and separation of the seeds from the "attached placenta" and the biomechanical indicators of the plants accompanying the possibilities of mechanized harvesting.

In 2016, the yield potential was studied on 43 progeny from F2 to F4 generation and a subjective-independent method was applied to evaluate their ability to retain their seeds until entering the threshing mechanism. As a result of this study, parental pairs were selected to be included in an incomplete diallel hybridization scheme.

In 40 promising progeny from F1 to F7 generation in 2019, the progress of the selection was reported regarding the strength of the "attached placenta" and the shape of the box. The offspring with improved qualities and good yield potential are included in hybridization according to an incomplete diallel scheme.

In the following year, 204 progeny, cultivars and introduced lines of sesame were subjected to the subjective-independent assessment, the new test of the Field test assessment and Sesaco's Shatering test. Those that showed good productive potential and ability to retain their seeds, according to the three tests, were included as parents in the known hybridization scheme.

In 2021, 264 progeny, cultivars and introduced lines were tested for the yield potential and the ability to retain their seeds according to the subjective-independent evaluation method and the field test.

To establish the genetic control of the "attached placenta" trait, 107 offspring from the F1 and F2 generation of two crosses were analyzed.

100 introduced lines of sesame from over 20 countries in the world, with different ecological-geographic origins, were studied, with the aim of including them in the Bulgarian breeding program.

3.2. Experimental designe and applied statistical methods for research.

3.2.1. Evaluation of a Sesame Collection with Non-shattering capsules.

Sesame lines with Non-shattering capsules have been studied in detail in the following directions and indicators:

Morphological signs

The plants in the every breeding lines whit Non-shattering capsules - stem, habitus, leaves, generative organs - buds, flowers, capsules and seeds . The lines, the object of the study, were also evaluated according to the indicators - productivity, early maturity and suitability for mechanized harvesting with a conventional harvester

3.2.2 Creation of the "attached placenta" sign.

The science-based method of selecting parent pairs to produce hybrids with "attached placenta" in the progeny and good yield potential included:

• Analysis of the genetic distance between the studied lines and varieties by means of the possibilities of cluster analysis (Tryfos, 1997; Mooi and Sarstedt, 2011)

• Establishing the modes of inheritance and the manifestation of heterosis (Mather, 1949) in some of the characters responsible for mechanized harvesting (lower stem, smaller number and short branches);

• The assessment of how long the capsules retain their seeds during ripening was based on subjective criteria (degree of openness, shape and manual shaking of the pods).

Biometric measurements to establish the morphological features of the test specimens and phenological observations were carried out on 20 randomized plants from each parent. Yield-related traits were measured.

Using the statistical program SPSS 13.0 for windows, the phenotypic correlations and Path-coefficients between the elements of the seed yield of a plant were established. Mathematical processing of the results was performed on three parental forms (using the averages for each parent) and separately. The percentage participation of the direct effects on yield, by determining their participation in the total direct effect. Indirect effects on yield represent the difference between phenotypic correlations and direct effects of individual traits (Martinov, 1978).

Factor analysis shows the percentage contribution of traits to each factor (Seiler and Stafford, 1985) and how their expression is suppressed by the interaction of genes in the genotype. The advantage of component analysis lies in demonstrating the genetic makeup of each factor.

As a result of the study, 6 parental forms included in an incomplete diallel hybridization scheme were released.

The genetic analysis of the progeny performed by d/a indicators, heterosis and inheritance of the trait in the broad and narrow sense were calculated according to the formulas of Mather (1949).

The presence or absence of epistasis was calculated using the means of the six generations (P1, P2, F1, F2, BCP1, BCP2) and checked using the formulas:

$A = 2*\Delta BCP1 - \Delta P1 - \Delta F1$

$B = 2*\Delta BCP2 - \Delta P2 - \Delta F1$

$C = 4*\Delta F2 - 2*\Delta F1 - \Delta P1 - \Delta P2$

By Mather (1949).

3.2.3. Methods for evaluating the materials received and the use of parent pairs in future breeding work with sesame.

The mechanism of retention and separation of the seeds from the "attached placenta" consists in justifying a method for assessing susceptibility to mechanized seed harvesting and in its application. This susceptibility depends on the following indicators:

• The share of seeds that are released from the pods during ripening - ms1, [%]. It includes the seeds that are released when the tip is opened or the pods are split lengthwise, and also the seeds that are released when the pods are gently turned upside down.

• The share of seeds remaining in the box after mechanical impact - mc2, [%];

• The share of seeds that left the boxes as a result of mechanical impact - ms3, [%].

In the present study, an inertial impact was applied to separate the seeds from the boxes using a Pendel apparatus stand (Figure 1).

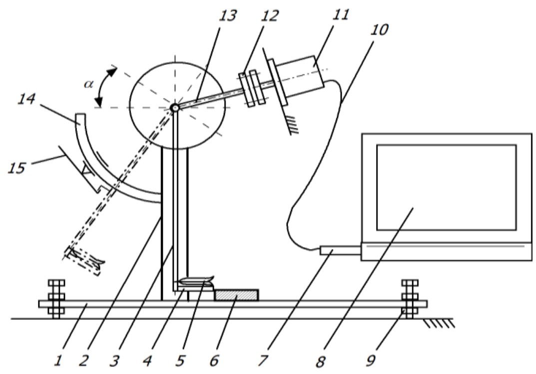


Figure 1. Bench for studying inertial separation of seeds from sesame pods.

1 - base, 2 - stand, 3 - pendulum rod, 4 - pendulum plate, 5 - tested capsules, 6 - counter, 7 - QSB-D counter, 8 - computer, 9 - leveling screws, 10 - cable, 11 - photo raster converter (FRP), 12 - coupling, 13 - pendulum shaft, 14 - scale, 15 - pendulum trigger.

In this case, the proportion of mc1 determines the susceptibility of each genotype to seed dispersal when the plants are shaken by wind or by low-speed mechanical impacts caused by harvesters. It is possible to harvest these seeds mechanically if the pods are not split open and the plants are fed into the machine without significant tilting. The portion of mc2 is indicative of seed retention, caused by the type and shape of the pods during ripening and, more specifically, the narrowing, presence and size of an opening or a longitudinal split. The proportion of mc3 is indicative of the stability of the connection between the seeds and the placenta. It is also informative about the susceptibility of the pods to release the seeds due to inertial impact.

The method of subjective-independent evaluation is justified as a result of this research.

The essence of the field method is described below.

The capsules are wrapped in permeable fabric and suspended from a rope, freely swaying in the wind and illuminated by the sun (Photos 1 and 2). When the seeds ripen and the pods burst, they are removed. Weigh the free seeds and the seeds retained in the capsules. In this way, the proportion of scattered seeds is counted until the entire crop reaches full maturity and is ready for harvesting.

This test mimics the effects of sun and wind in the field on sesame plants and their pods.

Picture 1. Capsules

Picture 2. Design of the experiment

According to this test, samples that retained 0 to 30% of their seeds were rated as dispersal. 30 to 60% seed retention classifies samples as low retention. 60 to 75% have samples with medium retention. Satisfactorily retain their seeds those samples where the percentage reaches 99, excellent - those that retain 100% of their seeds.

Sesaco's "Shattering test" serves to investigate the proportion of retained seeds in the capsules depending on the shattering of the chambers, placenta and membranes during ripening. This test includes two stages:

Testing the capsules in physiological maturity (Green test).

It includes the following steps:

G1: One capsules is cut from the middle of ten plants.

G2: Allow the capsules to dry completely.

G3: Each capsules is turned upside down without squeezing so as not to narrow the opening. The fallen seeds are collected and weighed.

G4: Each capsules is dropped three times from a height of 0.1m. The separated seeds are weighed.

G5: Separating the remaining seeds in the boxes and also weigh them

G6: The seed masses from steps G3, G4 and G5 are summed

G6 = G3+G4+G5

G7: Calculated:

SR1green = (G4 +G5)/ G6; SR2 green = G5/G6

Testing the capsules at full maturity (Dry test).

It includes the following steps:

D1: G1 is performed at full maturity of the sesame plants. It is recommended to close the top of the cut capsules with the thumb and forefinger.

D2: Let the capsules dry completely.

D3: Each capsules is turned upside down and individual seeds are drawn.

D4: Separate the remaining seeds in the capsules and also weigh them.

D5: The scattered seeds are determined by the dependency:

D5 = G6 – (D3 + D4)

D6: Sum the seed masses from steps D3, D4 and D5

D6 = D3 + D4 + D5

D7: Calculated:

SR1Dry = (D3 + D4)/ D6 SR2Dry = D4/ D6

$$\mathbf{SRA = (SR1_{Green} + SR2_{Green} + SR1_{Dry} + SR2_{Dry})/4*100\ \%}$$

Depending on the obtained SRA value, the varieties are classified as follows:

- SUS (super shattering) – varieties destroy their capsules completely when ripening and retain less than 10% of the seeds;

- SHA (shattering) – the pods of these varieties are partially destroyed and retain from 10% to 40% of the seeds;

- NSH (non-shattering) – with non-shattering capsules that hold from 40% to 80% of the seeds;

- DC (direct combine) – with capsules that hold more than 80% of the seeds;

- ID (indehiscent) – these varieties have pods that close at maturity and hold all the seeds.

3.2.4. Use of the trait for breeding purposes.

In order to establish the relationship of the sign "attached placenta" with the anatomical features of the capsules, the following indicators were analyzed:

Morphological measurements:

Sesame samples are examined according to three groups of indicators:

The first group includes: the share of retained seeds in the capsules - Ds, %, after they have dried in natural conditions and turned upside down for a different number of days for each sample until reaching 12% humidity. This position allows the seeds to leave the capsule when they are not attached to the placenta or when the capsule does not hold them due to other anatomical features. During drying, the wind speed varies from 2.0 to 10.3 m/s.

The second group of indicators is related to production and includes:

- The mass of seeds from one plant - ms1, g;
- The height of the stem - hst, cm ;
- The number of branches - Nbr;
- The number of capsules along the central stem - Ncst;
- The number of capsules on the branches – Ncbr.

The third group of indicators characterizes the shape and dimensions of the seed chamber (carpel) and includes:

- Length of the seminal chamber - lc, mm;
- Chamber width at the base, middle and top - bb, bm, bt, mm;
- Width of the narrowing - bn , mm and its distance from the base of the capsule - hn in natural (mm) and relative units (%).

The degree of narrowing of the boxes - Rn was calculated according to the dependence:

$$R_n = 100\frac{b_b - b_n}{b_b}, \%.$$

All measurements were performed in 10 replicates with an electronic caliper with an accuracy of 0.01 mm and averaged.

The genetic progress of the parameter number of branches per plant was performed using the analysis of variance. Estimation of variance components, phenotypic and genotypic variances was performed according to the method proposed by Burton and Devane (1953).

The following statistical estimates are used:

1. Environmental variance.

σ_e^2 = MSE

2. Phenotypic variance.

$\sigma_p^2 = \sigma_g^2 + \sigma_e^2$

3. Genotypic variance.

$\sigma_g^2 =$ MST- MSE,

where:

MSE - trial mean square error;

MST – mean square deviation;

r - repetitions.

4. Phenotypic coefficient of variation.

$$PCV = 100\frac{\sqrt{\sigma_p^2 x}}{x}$$

5. Genotypic coefficient of variation.

$$GCV = 100\frac{\sqrt{\sigma_g^2 x}}{x}$$

Where:

σ^2p - phenotypic variants;

σ^2g - genotypic variants;

x – general mean

Johnson et al. (1955) defined genetic progress and percentage of mean genetic progress:

$$GA = \frac{K\sigma_g^2\sqrt{\sigma_p^2}}{\sigma_p^2} = \frac{K\sigma_g^2}{\sqrt{\sigma_p^2}}$$

Where:

GA – genetic advance;

K – standard selection differential for 5% selection intensity (K = 2.063);

$$GAM = 100\frac{GA}{x}$$

Where:

GAM - genetic progress relative to mean, %;

GA - genetic advance;

X – general mean

Based on the results of the analyses, the most important factors influencing the retention of the seeds in the boxes are determined. These are included in a regression analysis to find equations in coded and natural form. All statistical analyzes were performed at a significance level of $\alpha=0.05$.

To create a core collection, two groups of indicators were evaluated. The first group covers the indicators responsible for keeping the seeds in the capsules, i.e. suitability of plants for mechanized harvesting. The second group of indicators refers to some of the productivity elements.

4. RESULTS AND DISCUSSION

4.1. Study of the source geneplasm

Breeding improvement work with sesame to obtain lines suitable for mechanized harvesting requires the creation of forms with non-shattering capsules. It is believed that such forms can arise by induced mutation and will solve the problem of mechanized harvesting in sesame.

In the period from 2001 to 2008, a complete agro-biological study was carried out on 22 Bulgarian breeding lines with non-shattering capsules (Stamatov, 2008). The newly developed non-shattering sesame genotypes, the subject of the present study, botanically belong to Sesamum indicum L, subsp. Bicarpellatum, var. vulgare.

The capsules of these sesame forms do not burst when the seeds ripen and they do not fall apart until they enter the threshing mechanism (Picture 3).

Picture 3. On the left, a non-shattering capsule, on the right, a shattering capsule

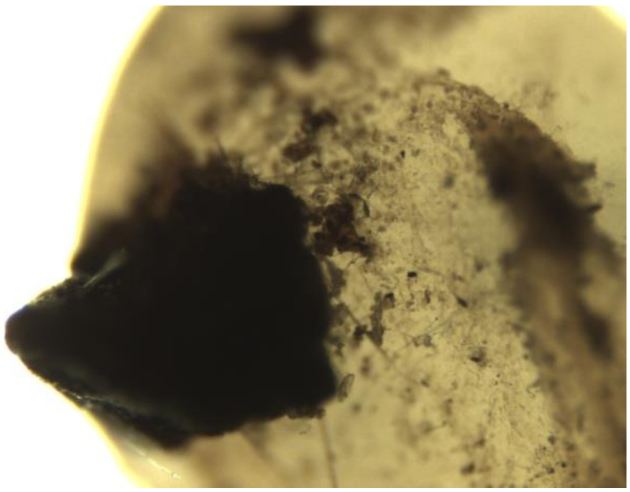
Table 1. Seed yields, losses from harvesting and germination

accessions	seed yield kg/da *				Losses, %	germination, %
	2004	2005	2006	средно		
Садово3850	53,8	87,8	34,1	58,6	28,2	72
Садово3859	55,4	67,4	29,7	50,8	29,3	42
Садово3958	55,9	55,6	35,7	49,1	27,8	61
Садово3959	61,2	88,3	44,9	64,8	26,8	75
Садово3959-2	49,2	80,3	33,7	54,4	31,3	70
Садово3959-3	46	71,4	36	51,1	32,4	69
Садово3962	55,7	79,6	38,9	58,1	28,8	60
Садово4045	53	70,6	31	51,5	33	43
Садово4047	49,2	78	34,8	54,0	39,6	64
Садово4050	57,9	87	32,5	59,1	34,2	61
Садово4051	57,2	85,7	35,5	59,5	30	62
Садово4053	56	88,2	38,4	60,9	35,3	69
Садово4055	100,8	36	38,1	58,3	31,4	69
Виктория	115,1	51,2	50,8	72,4	25,9	75
Садово4062	84	45,5	47,3	58,9	29,8	55

Садово4068	82,1	44,2	40,2	55,5	38,9	52
Садово4071	92,5	43,6	39,1	58,4	35,6	60
Садово4073	92,6	46,3	45	61,3	32,8	61
Садово4074	73,9	46,3	46,3	55,5	49,8	71
Садово4075	108,1	42,1	43,8	64,7	50,0	73
Садово4041	60	88,2	78,9	75,7	37,7	66
Садово4042	45,5	64,1	60,1	56,6	36,9	43
Средно				58,6	35,6	62,85

The reported results of the conducted Polish experiments show that these selection lines are low-yielding (50.8 - 75.7 kg/da). The sesame forms created so far are not 100% threshed. The losses of seeds after their harvesting in individual samples varied from 25.9 to 50% (table 1).

The capsules remain completely closed after drying, which does not allow all the seeds to be separated in the combat biter. Some of them pass through it without being crushed, and others, although partially crushed, do not release part of their seeds. Mechanical damage to threshed seeds reduces their germination (Picture 4).

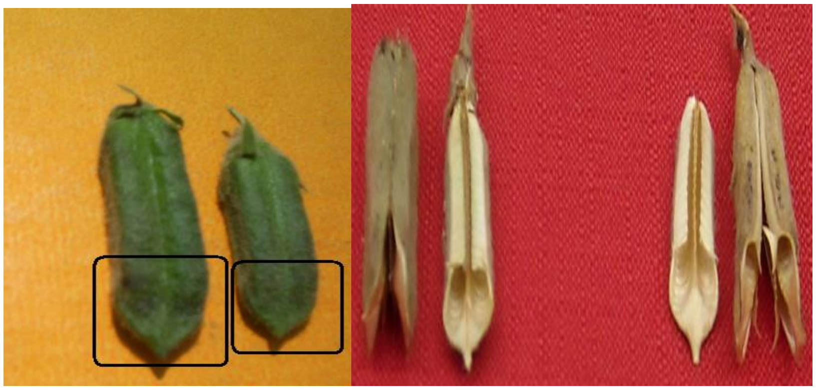


Picture 4. Injury to the seed caused by threshing with a conventional beater.

4.1.1. Selection of parent pairs to be included in hybridization program.

Showed the best productive capabilities of the studied lines with non-shattering capsules were included in hybridization with lines and varieties with bursting boxes according to their genetic distance established using cluster analysis.

The resulting hybrids in the F1 generation are characterized by the habit and capsule architecture typical of the shattering capsules parent. When following the offspring in the F2 generation, anatomical features of the box were found in 9 of them, which help to retain the seeds. The capsule, which is resistant to splitting, is characterized by a weaker pinch and a slight curvature at the tip of carpels. At full maturity, it opens slightly at the tip and its membrane does not separate, retaining the seeds (Picture 5).



Picture 5. On the left - a shattering capsule, on the right - resistant to splitting capsule

When tracing the mode of inheritance of the characters responsible for the architecture of the plant suitable for mechanized harvesting (shorter plants, small number and shorter branches), it was found that they are inherited dominantly in the direction of the parent 3959, which has non-shattering capsules. Hybrids are characterized by shorter plants, with fewer and shorter branches than their parents.

The strongest dominance is manifested in the inheritance of the branch length trait. With regard to this trait, two crosses show overdominance.

Correlation coefficients between seed yield per plant and yield elements showed that plant height, number of boxes on the central stem and branches were positively correlated with yield. Days to 50% flowering were negatively related to seed yield per plant.

Path-coefficient analysis shows a more realistic picture of the relationships between direct and indirect effects on seed yield than correlation analysis.

From the obtained results, it is found that the number of boxes on the central stem and branches have the highest direct effect on seed yield per plant (P1 = 1.08 and P2 = 1.20). The relative share occupied by these two indicators of the total direct effect on yield is 68.6 and 70.1%.

Central stem height had an indirect positive effect on yield (P = 1.71). The effect of central stem height on seed yield per plant was expressed by the phenotypic correlation r1,n-1 and r2,n-1. The correlation coefficients r = 0.856 and 0.784 show that the increase in the height of the stem leads to an increase in the number of boxes on the branches and the central stem.

The relationship of the direct effects on yield (number of boxes on the central stem and branches) with the other morphological and biological indicators showed that the number of boxes on the central stem was in direct negative relationship with the days to mass flowering (P = - 1.47). The height of the first box along the branch has a negative indirect effect on this indicator (P = - 1.35). The number of boxes on branches was directly affected by the total number of boxes and indirectly by the height of the central blade (P = 1.008 and P = 0.86). The phenotypic correlation between the two indicators is positive. The correlation coefficient (r = 0.461) has a relatively low value and is not mathematically proven. This shows that there is no genetic link between the two traits number of boxes on the central stem and branches and they are inherited independently of each other. This fact reveals great possibilities for optimizing the productivity of a plant, by parallel increasing the number of boxes along the central stem and branches. High yield traits do not correlate positively with those responsible for mechanized harvesting in sesame. This necessitates finding the direct and indirect effects on yield in each parent used in the breeding program.

4.2. Manifestation of the "attached placenta" sign. Selection of parent pairs and progeny. Study of the genetic control of the "attached placenta" sign

4.2.1. Study of the retention and release mechanism of the seeds from the "attached placenta". Biomechanical indicators of the obtained hybrids

The study of the offspring from the parent pairs selected in the hybridization program shows that they have higher yields than those of the forms with non-shattering capsules (105.3 - 131.3 kg/da) and possess qualities that make them suitable for mechanized harvesting (Table 2).

Table 2. Seed yields from a comparative variety trial

Accessions	Kg/da			
	2009	2010	2011	Mean

4077	117,8	115,2	118,1	117,0
4079	115,3	112	118,9	115,4
4081	138,5	128,3	139,1	135,3
4083 (Nevena)	128,9	136,4	128,4	131,2
4088	115,0	115,1	114,9	115,0
4089	122,0	128,3	120,3	123,5
4090	127,9	130,1	122,6	126,9
4091	119,6	125,1	121	121,9
4096	112,8	109	115,1	112,3
4097	114,2	110,2	121,3	115,2
4098	129,1	115,3	122,1	122,2
4099	125,9	125,3	128,9	126,7
4086 (Aida)	129,8	119,1	115,7	121,5
4094 (Valia)	130,3	132,4	131,1	131,3
			Mean	122,1

During the period 2011-2013, the best of them were sown in production areas to establish their suitability for mechanized harvesting with a conventional combine. Field losses ranged from 17 to 50% at different harvester settings and seed moisture. Two-thirds of these losses are due to the header and the remainder to unthreshed boxes. The quality of the seeds is poor, most of them have a damaged surface and reduced germination. During the processing of the threshed boxes in a laboratory, the so-called "attached placenta" was found in some of them. The seeds are attached to it and do not fall apart when ripening (Picture 6).

Picture 6. Seeds attached to the placenta

The biological signs of the plants of the investigated genotypes are presented in table 3. At seed humidity above 19% and box humidity above 33%, the plants are at technical maturity. Their pods are closed and no seeds are released. At a humidity of 14-15% for the seeds and 18-22% for the capsules, all the boxes are open. The majority of the seeds are attached to the placenta and can be harvested.

Table 3. Indicators of the studied genotypes

progeny	Yield seeds of a plant, g	Number capsules per plant	Mass seeds in a capsules, g	maturity, %					
				I-st		II-st		III-st	
				seed	capsules	seed	capsules	seed	capsules
Aida	7,9 ± 2,11	112 ± 6,2	0,070	20,5	35,8	15,1	22,5	10,2	18,5
Milenna	12,6 ± 3,04	175 ± 5,0	0,072	19,3	32,5	14,6	21,2	9,9	18,6
4090	8,5 ± 2,02	158 ± 5,4	0,053	20,3	34,1	14,9	18,3	10,2	18,5

During ripening, the humidity of the seeds and boxes decreases and significantly affects the change of parameters - mass of the seeds released from the boxes when they are rotated 180º (mc1) and mass of the seeds remaining in the boxes (mc2). With decreasing humidity, mc1 increases linearly and mc2 decreases linearly.

The proportion of seeds released when the boxes were smoothly turned upside down for the studied genotypes was different (Figure 1) and was mainly influenced by the cross-sectional shape of the box. The carpels of sesame pods split at their thickest part, causing rupture of the integument and the placenta that holds the seeds. The cross-section of the box in the Aida variety has the shape of a truncated pyramid, the wide side of which is at the base of the box, and the narrow side is located immediately below the top. The carpels are divided in the upper part and the seeds located in it have dried the most, and the placenta loses its properties to hold them sufficiently. In the case of the Milena variety and the selection line 4090, the narrow part of the truncated pyramid is at the base of the box and the splitting of the carpels is stronger.

Detachment of the seeds from the placenta is predetermined by the angle of placement and attachment of the seeds relative to the length of the placenta. This angle is about 30□ in the studied genotypes. Therefore, inertial force creates tension and bending at the point of attachment of the seed to the placenta. It is known that the effort required to break off seeds by bending is much smaller than that by tension (Ishpekov et al., 2012). Therefore, with equal inertial forces, more seeds are broken off by a transversely acting inertial force.

The increase in inertial force (Fin) leads to a directly proportional decrease in the share of seeds that remain in the boxes after the impact in all genotypes and speaks of the strength of the "attached placenta". The graph for variety Aida is steepest, indicating that this variety is most strongly influenced by Fin (Figure 2).

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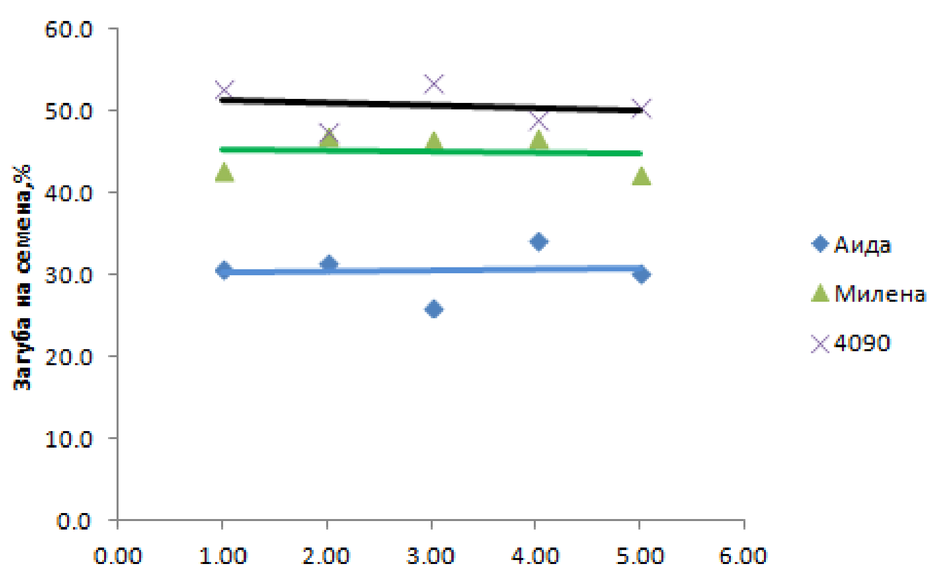

Figure 1. Seed loss from the smooth 180º rotation of the capsule

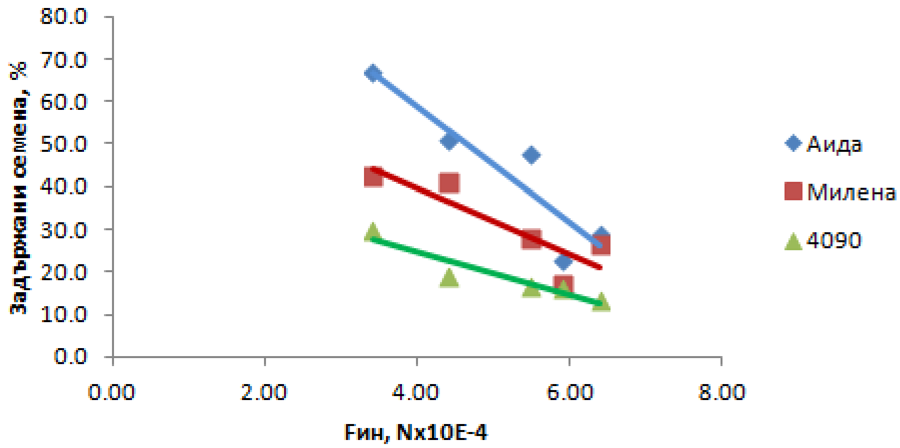

Figure 2. Share of the seeds remaining in the boxes after the inertial impact mc2, depending on the inertial force Fin.

The largest number of seeds left in the capsules after impact with a force of 3.4N x 10-4 is in the Aida variety, the dropped seeds make up about 2.1%. With the Milena variety, they are 14.4, and with the selection line 4090, they are 16.8%.

The bio-mechanical parameters of sesame plants during the seed harvesting period depend on the degree of maturity and humidity of the stems, pods and seeds.

The height of the stems of the variety Aida changes by □ 10.5 □ 15.4% compared to the average value and up to 26.7% compared to the year. For the Nevena variety, these values are □ 11.6 □ 16.9% and 31.3%, and for the Valya variety □ 5.2 □ 9.4% and 26.6%.

The height of the stems of the studied varieties varies from 0.945 to 1.80 m. Therefore, if the plants are harvested coelorastenically, the working organs must accommodate stems up to 1.8 m long. If harvesting is carried out when the plants are "on the root" a sufficient size of the area to which the mechanical action is applied to separate the seeds is necessary. It is determined by the height of that part of the stem on which the capsules are located. Taking into account that the considered varieties plant their fruit boxes at a greater height than 0.3□0.4 m above the soil, it can be assumed that this zone should be 1.5 m long (Stamatov, 2008 ; Deshev, 20015).

Under irrigated conditions of cultivation and technical maturity of the plants for the observed varieties and years, the average mass of single stems was from 31.0 to 54.8 grams, and their yield varied from 558 to 1424.8 kg/da. The mass of the capsules is from 30 to 35.8% compared to the mass of the stems. The mass of the seeds is from 12.8 to 17.3% of that of the stems and from 42.6 to 48.3% of the mass of the pods, and their yield varies from 148.3 to 171.5 kg/da.

In both degrees of maturity, the highest values for the friction angles were found in the pods and the lowest in the seeds.

4.2.2. Selection of parental pairs and evaluating in the resulting progeny.

The "attached placenta" realized at this stage still shows significant shortcomings. When the capsules open at maturity, contact of the placenta with air causes rapid desiccation and weakening. As a result, much of the seed is scattered in the field. Harvesting losses caused by seed scattering are also significant (picture 7). This necessitated the search for ways to anchor and strengthen the trait in the offspring through science-based methods of selection of the parent pairs and the offspring. Simultaneously with an increase in the strength of the "attached placenta" it is necessary to preserve the productive possibilities in the new hybrids. For this reason, in addition to the strength of the "attached placenta" in the offspring, the selection should also be carried out based on the seed yield from one plant.

Picture 7. Spreading the seeds when harvesting

The repeated individual teaming on subjective (gross) signs turned out to be poorly effective in the selection in this direction. In 2016, the application of the subjective-independent method for evaluating the mechanisms by which the different genotypes retain the seeds in their boxes marks the beginning of a qualitatively new stage in the selection and improvement work. It was expected to enable improved and accelerated evaluation of parents and hybrids by estimating the proportion of seed dispersal from pods due to momentum impact. This share is easily and quickly determined with a small number of boxes in technological maturity by means of a simple pendulum device, which generates and imparts the inertial impact on the boxes (Ishpekov and Stamatov, 2015).

For the first time, the method of subjective-independent assessment was applied when tracking 43 offspring from different generations of the selection process. Prospective offspring from F2 to F4 generation were followed.

Table 4. Progeny from different generations of sesame

№	progeny	mass seeds of capsule	i_1	i_2	i_3
1	f2/363-12-2	0.175	0.596	0	1.55

2	f3/362-5-1	0.076	1.033	1.033	0.615
3	f3/361-7-3-1	0.235	3.871	0.580	2.642
4	f4/355-9-2	0.040	0.256	6.090	1.510
5	f2/364-15	0.180	4.310	0.335	3.400
6	f2/365-26	0.130	4.110	0.135	1.400
7	f2/365-25	0.208	11.736	0.155	1.866
8	f3/361-6-1	0.188	4.970	0.378	2.180
9	f2/364-18	0.225	1.206	1.493	1.393
10	f2/363-9	0.085	1.246	0.937	0.806
11	f2/364-6	0.145	17.686	0.076	1.196
12	f3/361-7-8-1	0.2	7.020	0.032	2.770
13	f3/361-4-1	0.208	19.270	0.071	1.270
14	f2/363-20-1	0.098	0.346	6.180	1.030
15	f3/361-6-2	0.222	87.010	0.021	1.870
16	f4/355-2-1	0.250	1.560	1.56	2.765
17	f3/361-4-2-1	0.177	3.190	0.523	1.851
18	f3/361-7-6-1	0.167	1.902	0.760	0.760
19	f4/355-6-1	0.080	0.985	1.311	1.688
20	f2/363-13-1	0.156	1.33	1.173	1.462
21	f4/355-3-2-2	0.125	1.003	1.370	1.313
22	f2/364-20	0.187	4.442	0.404	0.471
23	f4/355-6-2	0.217	1.870	1.036	1.433
24	f3/361-3-6	0.220	2.108	0.838	0.966
25	f3/361-6-3	0.182	0.838333	2.561	3.694
26	f3/362-2-1	0.220	4.793	0.428	0.500
27	f2/365-27	0.250	3.154	0.605	0.662
28	f3/361-7-2	0.155	5.715	0.267	0.28
29	f3/361-7-9	0.112	3.292	0.380	0.331
30	f2/364-4	0.255	3.801	0.466	0.472
31	f2/364-16-1	0.230	2.560	0.694	0.765
32	f2/364-8	0.055	0.830	1.413	1.413
33	f2/365-28	0.055	0.390	3.423	3.100
34	f3/361-7-1-2	0.192	3.517	0.512	0.618
35	f3/361-7-1-1	0.160	10.47	0.166	0.184
36	f2/365-6	0.185	11.14	0.230	0.304
37	f2/363-14	0.070	1.580	0.746	0.746
38	f2/363-12-1	0.115	2.466	0.463	0.292
39	f2/363-19	0.217	4.292	0.391	0.398
40	f2/365-17-1	0.070	1.538	0.810	1.170
41	f2/365-18	0.102	3.435	0.356	0.302
42	f2/365-20-1	0.160	16.453	0.181	0.274
43	f3/361-7-4-1	0.147	4.241	0.373	0.441

The results of the measurements (reflected in table 4) show that 12 offspring are characterized by the largest mass of seeds in a capsule. One capsule of them contains from 0.2 to 0.255 grams of seeds. With the lowest mass of the seeds in a capsule (below 0.1 gram) are 6 offspring - with a mass of 0.04 to 0.098 grams. The remaining 25 progeny produced seeds per capsule weighing between 0.1 to 0.19 grams.

The progeny that lack anatomical mechanisms for holding the seeds and scatter them when shaken are the majority of the studied genotypes. Twenty-three of the progeny studied were high i1. Three of the genotypes have high i2. It is noteworthy that these progeny produce pods with very low seed mass. Sesame forms with high i3 values are characterized by a strong placenta and retain their seeds until an inertial force is applied to them, three of the progeny studied have a strong seed-placenta connection. The remaining 14 offspring have indices close in value. According to their size, they retain their seeds thanks to having a strong connection between the seeds and the placenta or narrowing of the box along its length. Progeny with high i2 influence the ratio of seed mass per capsule.

The results of the correlation analysis show a negative effect of the narrowing of the capsule along its length on the mass of the seeds in the box. The correlation coefficient r = - 0.432 is proven to a high degree. From the correlation analysis of the studied progeny, it is established that there is a positive linear relationship between i1 and i3, which is a demonstration of the results obtained from the indices close in value in individual offspring.

Path - the coefficient analysis makes it possible to discover hidden relationships between the studied indices and the mass of seeds in a capsule.

The results presented in Table 5 show that the possibilities of influencing the seed mass through i1 and i2 are negligible. The direct effect of increasing seed mass by increasing i1 is shown by the low value of the coefficient (0.113). The negative impact of i2 is demonstrated by the direct effect of the coefficient with a value of (-0.401). For i3, the direct coefficient is also negative (-0.026), but the seed mass can be increased by the correlation that exists between i1 and i3. The value of the indirect coefficient (0.04) is higher than the direct one.

Table 5. Path - coefficient analysis between the studied indicators

	i_1	I_2	I_3	Phenotype correlations
i_1	**0.113**	0.116	-0.01	0.220
I_2	-0.032	**-0.401**	0.01	-0.432
I_3	0.040	0.019	**-0.026**	0.034

The investigated signs indicate two significant components with a weight above unity, explained at 86.5 % (table 6). The first significant component explained at 43.03% includes seed mass per capsule, i1 and i2. The second significant component explained at 71% includes i3 (Tables 6 and 7).

According to Stamatov and Deshev (2012), the traits from the individual components are transmitted independently of each other in the offspring.

Table 6. Explanation of total variance

Components	Explantion	Cumulative%
1	1.721597	43.03991
2	1.135599	71.42988
3	0.603106	86.50753
4	0.539699	100

Table 7. Component matrix

signs	components	
	1	2
mass seeds of capsule	0.681199	
i_1	0.724925	
I_2	-0.7312	
I_3		0.767753

The location of the studied indicators in the component plane is shown in figure 3. It shows that i1 and the mass of seeds in a capsule are positively related to the two significant factors, i2 is negative to both components, and i3 is positive to the second principal component and negative to the first.

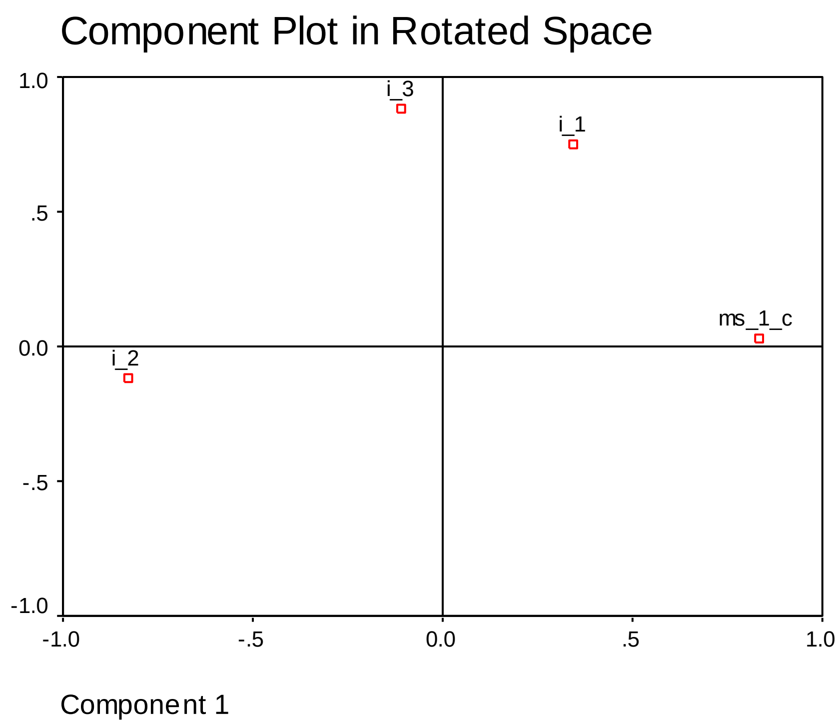

Figure 3. Location of the studied signs in the component plane

Figure 4 demonstrates the relationship of the studied offspring to the significant components in the factorial plane. From it, it is established that offspring that disperse their seeds and are characterized by a high seed yield relate positively to the two significant factors. Offspring with numbers 5, 6, and 33 relate positively to factor 2 and negatively to factor 1. These offspring have a sufficiently strong “attached placenta”.

Progeny 33 also has anatomical features of the box that allow it to retain its seeds. This offspring is approximated in the factorial plane to the offspring whose shape predetermines seed retention.

In order to anchor and increase the strength of the "attached placenta" without reducing seed pod mass, future breeding work should exploit the direct negative relationship that exists between i2 with seed pod mass and the latent relationship that exists between i1 and i3. In this sense, offspring from the right half of the factorial plane should be used for future crosses. Success should be expected if straight and reciprocal crosses are made between 33 and 12 progeny and 5 and 15 progeny. The offspring originate from different clusters, which guarantees their genetic distance.

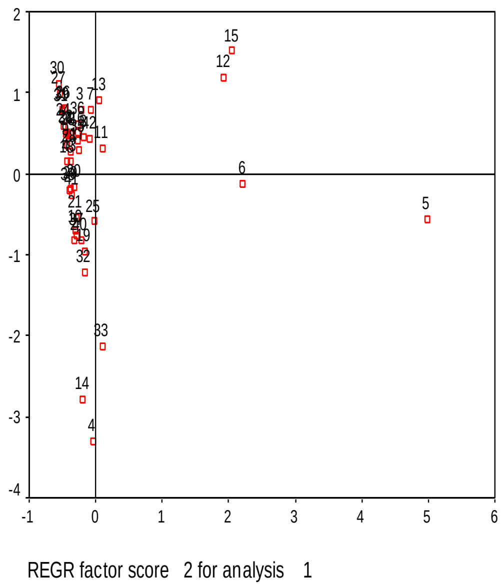

Figure 4. Location of the studied samples in the component plane

In 2018, a Field method for evaluating the feature was added.

30 samples were analyzed. The retained seeds in the boxes according to the Polish method are from 10 to 100%. The evaluation of these samples by the subjective-independent method showed that most of them have a high index 2 (table 8).

The hybrid offspring 353-6-2, 361-7-3-2-1 and 369-12 retain their seeds to the greatest extent (100%). Of these, the ability to separate a large part of its seeds after an applied inertial load (high index.

Table 8. Sesame samples that have the ability to retain their seeds at maturity

№	accession	% retained seeds of field method	indices
1	Nevena	76.2	2
2	Aida	10.0	3
3	Valya	24.0	3
4	4086	61.0	2
5	B 4000155	77.0	2
6	B 4000156	49.4	3
7	B 4000-162	50.2	2
8	463	56.1	2
9	464	83.1	3
10	328-1-1-1	50.2	2
11	353-6-2	100,0	2
12	354-13-1	71.0	2
13	355-6-1	44.0	2
14	355-9-1	80.9	2
15	355-16-2	72.9	3
16	361-4-2-2	61.4	2
17	361-6-2	70.3	2
18	361-7-2	41.3	2
19	361-7-3-2-1	100.0	3
20	361-4-2-2	60.0	2
21	363-12-2	43.1	2
22	363-19	41.1	2
23	365-26	46.0	2
24	369-2-2	42.9	2
25	369-3-2	72.2	2
26	369-5	50.0	2
27	369-12	100,0	2
28	373-3	71.3	2
29	373-6	93.2	2
30	373-7	53.4	2

3) owns the sample with selection number 361-7-3-2-1. The other two specimens did not release their seeds after applying an inertial load. In order to separate the seeds, it is necessary to apply impact and rubbing forces on the boxes (high index 2).

The samples that keep their seeds from 70 to 100% are 9. The group that keeps their seeds from 50 to 70% also includes 9 samples. The remaining 9 samples retain their seeds from 10 to 50%. The varieties Aida - 10% and Valya - 24% have the weakest ability for this. They release their seeds when subjected to inertial impact (high index 3).

Seed yield and the elements that form it are also important in selecting genotypes that are suitable for mechanized harvesting.

The highest yield from one plant forms the Nevena variety - an average of 13.7 grams. More than 10 grams of plant form 5 more samples. Between 5 and 10 g form most of the samples.

Introduced samples with numbers 463 and 464 are characterized by the lowest yield per plant, 1.7 and 1.2 g, respectively. The plants in the group have a height of 101.6 to 138.0 cm, form 0.4 to 4 number of branches of the first order. The boxes that form along the central stem vary from 29 to 48.6 pieces, and along the branches from 1.8 to 119.8.

Dependency analysis showed that there is a direct positive relationship between yield elements. The obtained correlation coefficients prove that in order to increase the yield potential in the hybrid offspring, it is possible to perform the selection independently by means of the signs - number of boxes on the central stem and branches. This achievement in the Bulgarian selection was obtained and continued by the work of Deshev (2015).

The dissociation of the correlation coefficients through their direct and indirect influence makes it possible to evaluate the hidden relationships between the studied indicators. The data from the Path-coefficient analysis show that there is a direct positive relationship between the Polish test and the indices of the subjective-independent method. Genotypes that keep their seeds in the capsules have a lower yield of seeds per plant. The indirect coefficient of -0.273 is obtained from the correlation that exists between the height of the central stem and the seed mass of a plant. In such a case, the seed-retaining genotypes should have a higher number of branch boxes (indirect coefficient 0.215) derived from the correlation that exists between the number of branch boxes and the number of branches.

The considered groups of indicators are divided into two significant components explained at 70.842% (table 9). The first of them is explained at 50.188% and covers the elements of productivity - mass of seeds in a plant, height of the central stem, number of branches, number ofcapsules on the central stem and on the branches.

The second component includes the percentage of retained seeds and the indices obtained through the subjective-independent assessment (Table 10).

Table 9. Significant components

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.6241	51.7727	51.7727	3.624091	51.7727	51.773	3.513164	50.18805	50.1881
2	1.3349	19.0700	70.8427	1.334899	19.07	70.843	1.445827	20.65467	70.8427
3	0.7158	10.2255	81.0682						
4	0.6901	9.8581	90.9263						
5	0.3271	4.6725	95.5988						
6	0.2383	3.4045	99.0034						
7	0.0698	0.9966	100.0000						

Extraction Method: Principal Component Analysis

The indices obtained from the subjectively independent method and the number of branches relate positively to both significant factors in the component plane. The rest of the productivity elements are positive in relation to component 1 and negative in relation to component 2, and the indicator - percentage of saved seed in the boxes is positively directed towards component 2 and negatively towards component 1 (figure 5).

Table 10. Component matrix

	Component	
	1	2
Field test	-.178	.814
indices	.027	.784
Seed mass of a plant	.895	-.135
Height of central stem	.809	-.193
Number of branches	.854	.119
Number of capsules of central stem	.638	-.314
Number of capsules of branches	.943	.009

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 3 iterations.

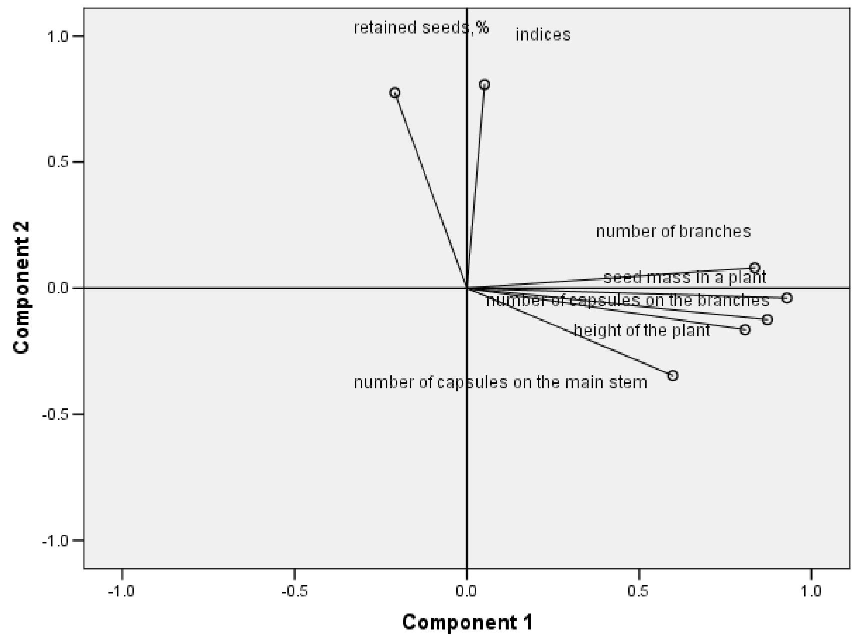

Figure 5. Component plane of the studied indicators

The location of the studied samples in the component plane is shown in figure 6. From it, it is found that the samples that retain their seeds to the greatest extent are located in the quadrant of percentage of seeds preserved. Samples characterized by high yield and good ability to retain their seeds form the heart-shaped collection. They are located in the right quadrants of the component plane, which covers the indices obtained by the subjective-independent method and the elements of productivity. Samples occupying the lower left quadrant of the component plane are characterized by a poor ability to retain their seeds and produce a low plant yield.

Component and cluster analysis (Figure 7) allow the parent pairs to be selected for hybridization.

The dendrograms show that Valya, Aida and Nevena varieties can be crossed with selection lines 361-7-3-2, 369-12 and 353-6-2. All of these are good sources of variation due to their distance from the center of the component plane. Another indication of this is that

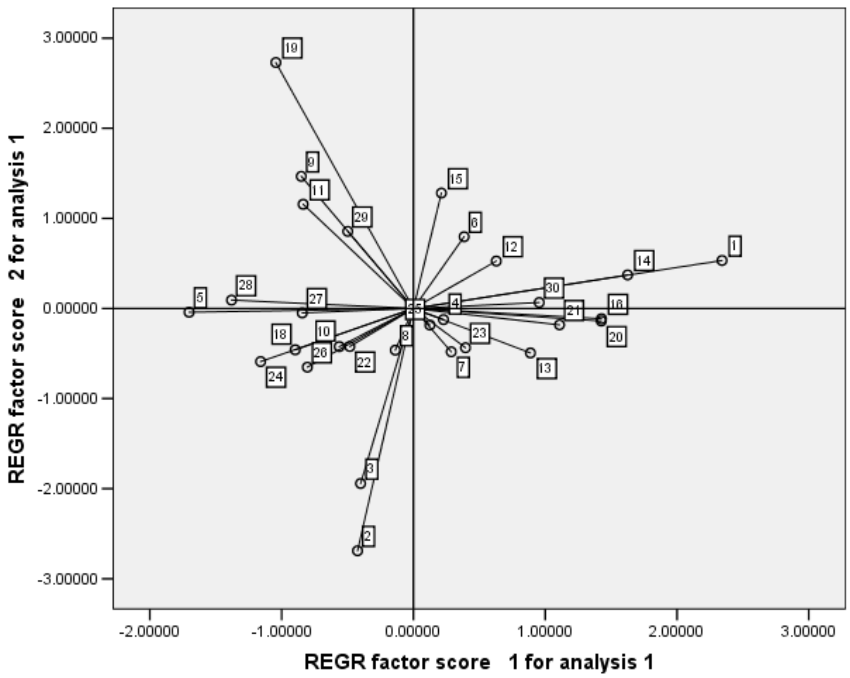

Figure 6. Component plane of the studied samples

the parents are genetically far enough apart that they would produce high-yielding offspring that do not scatter their seeds at maturity.

4.2.3. Study of the genetic control of mechanisms for retaining the seeds from the sesame capsules.

Of the progeny produced in the F1 generation of cross 373, 69% were high i1 and 31% were high i2. In this generation, there are no offspring with high i3, i.e. there is no manifestation of the "attached placenta" trait. 75% of the offspring in the F2 generation have a high i2, and the remaining 25% have an "attached placenta". Scattering offspring reappeared in the F3 generation and accounted for 72% of them. Offspring that retain their seeds thanks to anatomical features of the box (high i2) are 21%, and those with a healthy "attached placenta" (high i3) are the remaining 7%.

From the genetic analysis performed in the F1 generation, it is established that i1 is inherited by incomplete dominance over the parent with a lower manifestation of the i1 index. There is no heterosis effect in the inheritance of

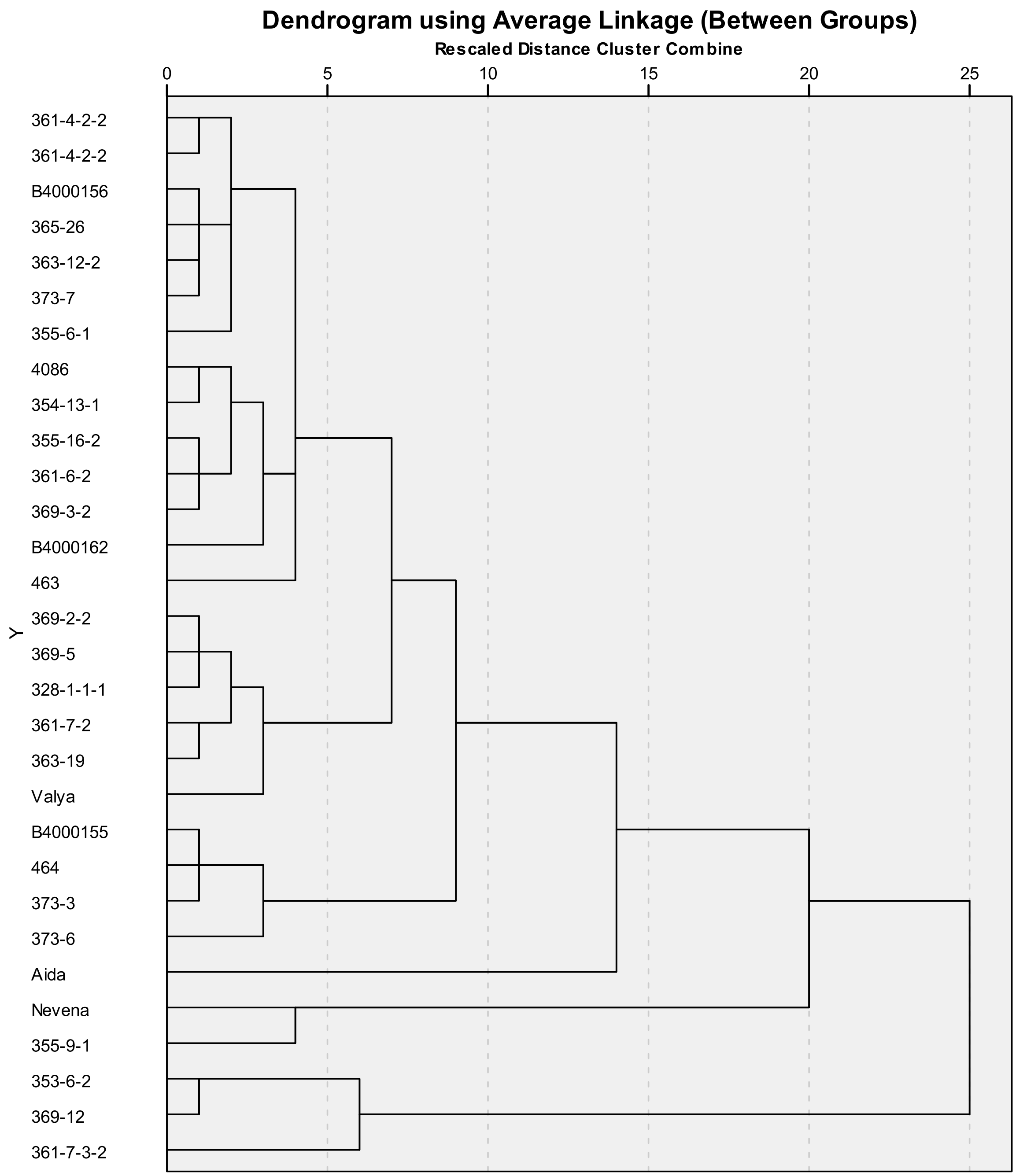

Figure 7. Clustering of samples

sign. The test of the null hypothesis shows that it is valid, which means that the index manifests itself through an additive-dominant pattern.

Inheritance of i2 occurs through incomplete dominance of the parent with a higher i2 index. The heterosis effect when inheriting this trait is 14.1%. The proven null hypothesis shows that also for this trait, inheritance takes place by means of an additive-dominant model.

Inheritance of the i3 index occurs through incomplete dominance of the parent with a stronger "attached placenta". There is no heterosis effect and inheritance is additive-dominant.

Phenotypic coefficients of variation (PCV) for all three indices exceeded genotypic coefficients (GCV). The higher value of the phenotypic variance gives us reason to claim that the manifestation of the trait (indices) is controlled by the genotype (hereditary variation), the environment and the interaction of the genotype and the environment.

From the genetic analysis performed in the F1 generation of cross 374, it was found that i1 is inherited by overdominance of the parent with lower i1. Heterosis is clearly expressed with 36.6%. Testing the null hypothesis shows that it is invalid, meaning that the trait occurs through epistasis. Inheritance of i2 occurs through overdominance of the parent with lower i2. There is no heterosis effect in the inheritance of this index. The null hypothesis has not been proven, which shows that even with this trait, inheritance takes place through epistasis. Inheritance of i3 is by overdominance of the parent with a weaker "attached placenta". The occurrence of a heterosis effect is absent and the inheritance of the trait is through epistasis.

Phenotypic coefficients of variation (PCV) for i1 and i2 exceed genotypic coefficients (GCV). The higher value of the phenotypic variance gives reason to claim that the manifestation of the trait (indices) is controlled by the genotype (heritable variation), the environment and the interaction of the genotype and the environment. The phenotypic coefficient of variation has a lower value than the genotypic one at the manifestation of i3, this indicates a stronger genetic control. And in this cross, the team can be effective based on these traits and their phenotypic manifestation. This fact is a good indicator of genetic potential.

4.3. Use of the trait "attached placenta" for selection aims.

4.3.1. Application of sample evaluation methods

In 2017, as a result of personal correspondence, 11 samples of sesame were imported from Portugal originating in the USA. They are intended for direct combining (DC) according to the Sesaco classification. Specimens catalog numbers 240, 460, 463, 464, 816 and 465 have indehiscent carpels and the seeds are firmly attached to the placenta.

Model with catalog number 504 has unbreakable cases. All introduced specimens have calyxes almost twice as long as the native forms. Their boxes reach a length of 5.2 to 5.4 cm.

Of the eleven specimens tested, introduced from Portugal, ten had the ability to retain their seeds in the pods. Only sample 816 is not suitable for mechanized harvesting due to self-dispersion of the seeds.

The three Bulgarian varieties Aida, Valya and Nevena retain the seeds in their pods thanks to the "attached placenta" feature and are therefore most suitable for inertial threshing. The rest of the samples retain their seeds due to the narrowing of the boxes with a decrease in humidity and are therefore suitable for harvesting by classical threshing at seed moisture below 7%, but with the possibility of losses due to poor threshing. The two ways of keeping the seeds in the boxes are indicators of the directions of selection of sesame, intended for mechanized harvesting in Bulgaria and in other countries.

4.3.2. Relation of the "attached placenta" sign to anatomical features of the capsule to hold the seeds.

The presence and degree of narrowing of the seed chamber in the Bulgarian sesame collection, suitable for mechanized harvesting, was determined. It has been proven that its distance from the base of the capsule has a significant effect on the retention of the seeds in the boxes during ripening. The average number of branches in one plant, which form the samples from the Bulgarian selection of non-dispersing genotypes, is 2.2. A direct relationship was established between the number of branches and the width of the seminal chamber in its middle part. With an increased number of branches, a greater degree of narrowing of the chamber is observed. A statistically adequate regression model with a high value of the multiple correlation coefficient was obtained, which included all factors that significantly affected the proportion of seeds retained in the boxes when positioned upside down until reaching 12% moisture under natural conditions and at a wind speed of 2 to 10.3 m/s. The model testifies that the proportion of retained seeds is most strongly influenced by the distance of the narrowing of the box from its base, followed by the force with which the placenta retains the seeds. The average number of branches from one plant has the weakest, but significant and directly proportional influence on the share of retained seeds in the capsules.

4.3.3. Creation of core collections

Anatomical features of the capsule to hold the seeds during ripening and "attached placenta" are possessed by 30 specimens. The remaining 70 specimens in the studied collection do not have the ability to retain their seeds and are not subject to further consideration. The preserved seeds in the boxes according to the Polish test range from 10 to 100%. The assessment of these samples by the subjective-independent method shows that most of them have a high index 2.

Hybrid offspring with selection numbers 353-6-2, 361-7-3-2-1 and 369-12 retain their seeds to the greatest extent (100%). Among them, the sample with selection number 361-7-3-2-1 has the ability to separate a large part of its seeds after an applied inertial load (high index 3). The other two specimens did not release their seeds after applying an inertial load. In order to separate the seeds, it is necessary to apply shocks and rubbing on the capsules (high index 2), (Ishpekov and Stamatov, 2015 b; Ishpekov et al., 2015 a).

The samples that keep their seeds from 70 to 100% are 9. The group that keeps their seeds from 50 to 70% also includes 9 pieces. The remaining 9 samples retain their seeds from 10 to 50%. The varieties Aida - 10% and Valya - 24% have the weakest ability for this quality. They release their seeds when subjected to inertial impact (high index 3).

Seed yield and the elements that form it are also important in the selection of genotypes suitable for mechanized harvesting.

The highest yield from one plant is the Nevena variety, 13.7 grams on average. More than 10 grams of plant form 5 more samples. Between 5 and 10 grams form most of the samples.

Introduced samples numbered 463 and 464 (1.7 and 1.2 grams) are characterized by the lowest yield per plant. The plants in the group are 101.6 to 138.0 cm tall and form 0.4 to 4 first-order branches. The boxes that form along the central stem vary from 29 to 48.6 pieces, and along the branches from 1.8 to 119.8.

There is a direct positive correlation between yield elements. It was established that in order to increase the yield potential in the hybrid offspring, it is possible to perform the selection independently through the signs - number of boxes on the central stem and branches. There is a direct positive correlation between the field test and the indices of the subjective-independent method.

Samples characterized by high yield and good ability to retain their seeds form the heart-shaped collection. They have high indexes obtained by the subjective-independent method.

4.3.4. Comparison of sample evaluation methods

In order to choose the most suitable method for evaluating parental pairs and hybrids with regard to the "attached placenta" trait, it is necessary to make a comparison between the methods used.

The results of the factor analysis show the principle influence of each indicator (Brejda, 1998; Seiler and Stafford, 1979).

Based on this, the studied genotypes are divided into two groups (tables 11 and 12). The first group describes 41.792% of the total dispersion and combines the SRA indicator and the i2 and i3 indices. They increase with increasing resistance to hold the seeds in the pods. The second group includes the Polish test and i1, which describes 58.208% of the variance. Both indices increase with increasing susceptibility to seed dispersal.

Table 11. Results of the factor analysis

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.743	34.854	34.854	1.743	34.854	34.854	1.738	34.760	34.760
2	1.168	23.354	58.207	1.168	23.354	58.207	1.172	23.448	58.207
3	0.993	19.862	78.069						
4	0.814	16.283	94.352						
5	0.282	5.648	100.000						

Table 12. Significant components

signs	Component	
	1	2
i_0		-0.609
i_1		0.760
i_2	0.835	
i_3	-0.886	
SRA	0.504	

At a significance level $\alpha = 0.05$, the differences between the SRA indicator and all indices of the Bulgarian method are statistically significant (table 13). There is no significant difference between SRA and the average of i2 and i3 in terms of both mean and root mean square deviation. This is also evident from the Box and Whiskers Plot (Figure 8)

Table 13. T-test results for proving differences between the studied indicators

Compared parameters	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p
SRA	0,535622	0,369250	203	0,102055	0,482296	3,01488	202	0,002901
i0	0,433567	0,264333						
SRA	0,535622	0,369250	203	0,400683	0,469832	12,15085	202	0,000000
i1	0,134939	0,294212						
SRA	0,535622	0,369250	203	-0,341487	1,105858	-4,39970	202	0,000018
i2	0,877109	1,061784						
SRA	0,535622	0,369250	203	0,366491	0,379195	13,77045	202	0,000000
i3	0,169131	0,095362						
SRA	**0,535622**	**0,369250**	**203**	**0,012502**	**0,608543**	**0,29271**	**202**	**0,770047**
(i2+i3)/2	**0,523120**	**0,505182**						

From Table 13, it is found that the mean values and root mean square deviations of the field method i0 and i1 and of the SRA indicator are close and give the impression that they unambiguously assess the susceptibility to mechanized harvesting of sesame varieties. This impression is wrong because indices and the SRA measure different and opposite properties.

The two indices evaluate the susceptibility of the varieties to self-seeding, and the SRA indicator – the resistance to retention of the seeds in the boxes. Therefore, in the present study, the close statistical characteristics of the field test and i1 and the SRA indicator are coincidental.

The smallest is the root mean square deviation of the experimental data for the i3 index. It is indicative of only one sign of the variety, and that is the strength with which the "attached placenta" holds the seeds in the pods.

The i2 index is indicative of the retention of the seeds caused by the anatomical features of the box. Its values have the largest standard deviation (dispersion) due to the large number of signs that determine it. One of them is the force with which the membrane presses the seeds, the second is the degree of constriction of the box and the third is the height at which the constriction is located relative to the base of the capsules.

After averaging the experimental data for i2 and i3, a summary index is obtained that is not significantly different from the SRA parameter, both in terms of their average values and root mean square deviations. This result proves that when we eliminate the signs that determine the release of the seeds from the boxes, then the Bulgarian method becomes comparable to the Sesaco method.

The conditions for applying both methods should also be taken into account. The Sesaco test is applied without any experimental equipment, while the Bulgarian method requires a pendulum apparatus (Ishpekov et al., 2015).

5. CONCLUSIONS

1. Understanding the reasons for the ability of the capsules to retain seeds, the peculiarities in the architecture and morphology of the capsules, as well as their genetic nature, will help approaches in the selection of parental pairs and the selection of progeny.

2. Placenta attachment scar is amplified in subsequent post-F1 generations.

3. The collection of sesame cultivars, introduced specimens and hybrid materials was studied in terms of their ability to retain their seeds at maturity and their productive potential.

4. A model of a plant suitable for mechanized harvesting was made from the existing specimen collection.

5. A core collection of specimens suitable for mechanized harvesting has been compiled. The Bulgarian sesame collection showed excellent options for selecting genotypes that retain their seeds at maturity. It revealed a broad genetic basis for different mechanisms by which individual genotypes retain seeds in their fruiting bodies.

6. Increasing the separation of the apex of the capsule does not weaken the attached placenta.

7. The presence and degree of narrowing of the seed chamber in the Bulgarian sesame collection, suitable for mechanized harvesting, was determined. It has been proven that its distance from the base of the capsule significantly affects the retention of the seeds in the boxes during ripening.

8. The average number of branches in one plant, which form the sesame from the Bulgarian selection of non-split genotypes, is 2.2.

9. A direct relationship was established between the number of branches and the width of the seminal chamber in the middle and part. With an increased number of branches, a greater degree of narrowing of the chamber is observed.

10. A statistically adequate regression model with a high value of the multiple correlation coefficient was obtained, which included all factors that significantly influenced the proportion of seeds retained in the capsules when positioned upside down until reaching 12% moisture in natural conditions and at a wind speed of 2 to 10.3 m/s.

11. In the new materials, the possibility of an independent test according to the number of boxes on the central stem and branches is preserved

12. The SRA indicator from Sesaco's Shattering test and the indices of the Bulgarian method give close estimates, between which there are statistically significant differences at the significance level $\alpha = 0.05$, which is explained by the different ways of their determination.

13. From a breeding point of view, the Bulgarian method is more informative because it distinguishes the reasons that lead to retention of seeds. They can be both the attached placenta and the numerous anatomical features of the capsule. Therefore, the application of the Bulgarian method facilitates the selection of sesame varieties that are intended for mechanized harvesting.

6. CONTRIBUTIONS

6.1. Contributions of original character

1. In an original Bulgarian sesame gene-plasma, the trait "attached placenta" was found;

2. Bulgarian methods for evaluating the force with which the "attached placenta" holds the seeds in the sesame box until they enter the threshing mechanism are substantiated;

3. The relationship between the sign and other anatomical features of the box has been proven;

4. A morphological feature has been defined that contributes to the anchoring and strengthening of the "attached placenta" feature. It has been found that the increased number of branches in plants enhances the strength of the "attached placenta".

6.2. Contributions of a scientific nature

1. Specimens with non-bursting sesame boxes cannot fully meet the requirements for mechanized harvesting of the crop;

2. It has been established that the lines with non-rupturing boxes are an excellent donor for the realization of the signs - "attached placenta" in the offspring and appropriate plant architecture, suitable for mechanized harvesting;

3. It has been confirmed that the trait "attached placenta" is controlled by recessive genes;

4. The trait is inherited through dominant or recessive epistasis;

5. It has been proven that, in addition to the "attached placenta", the signs - narrowing of the box, as well as the membrane covering them, also play a role in keeping the seeds in the boxes;

6. The role of the genetically distant samples in healing and strengthening the sign "attached placenta" has been proven.

6.3. Contributions with applied meaning

1. A scientifically based method for selecting parent pairs and teaming in hybrid offspring has been developed and applied;

2. For mechanized harvesting of sesame, it is necessary that the working bodies for cutting and feeding the stalks of each harvested row have a throughput of more than 2.69 kg/s, and those for threshing and primary cleaning of the crop - more than 0.35 kg/s .

7. LIST OF PUBLICATIONS-RELATED THE DISSERTATION

1.Ishpekov S., N. Naydenov, R. Zaykov, St. Stamatov, D. Ruschev (2017). Releasing of seeds by a lateral mechanical impact for feeding sesame stems into harvester. AgricEngInt: CIGR Journal Open access at http://www.cigrjournal.org .19 (4): 54-60.

2. Stamatov St., M. Deshev (**2018).** Review of the Methods for Breeding of Sesame (Sesamum indicum L.) in Bulgaria. Bulgarian Journal of Agricultural Science, ISSN 1310-0351, 24 (3): 411-416.

3. Stamatov St., N. Velcheva, M. Deshev (2018). Introduced sesame accessions as donors of useful qualities for breeding of mechanized harvesting cultivars**.** *Bulgarian Journal of Agricultural Science*, 24 (5): 820–824.

4. Rui Nobre, Stanislav Stamatov, Manol Deshev, Stoyan Ishpekov 2019. Evaluation of suitability for mechanized harvesting of sesame genotypes, introduced in Portugal. Bulgarian Journal of Agricultural Science, 25 (No 4) 2019, 810–815

5. Stanislav STAMATOV, Stoyan ISHPEKOV, Manol DESHEV, Elena VANKOVA, Manol DALLEV 2020. Seed Retaining Model of Non-Dehiscence Sesame (Sesamum indicum L.) Genotipes at Ripening. Scientific Papers. Series A. Agronomy, Vol. LXIII, No. 1, 2020 ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785, p 541-546 web of science, web of science