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Correlations of confectionary seed traits in different head zones sunflower

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Abstract: It is proposed to study the qualities of sunflower seeds in three zones of location in the head. Moderate negative correlations of the sign of the number of lateral heads (branching) in sunflower lines from the mass of 1000 seeds, the number of rows, seeds in a row, the total number of seeds and the diameter of the head were established (r = –0.5 to –0.53* on the Chedokk scale). The dependence of the number of seeds in the head on its size was confirmed (r = 0.83). In particular, we obtained a high positive correlation between the signs of the number of rows in the head and the number of seeds in the row with the size of the head (0.71 and 0.72). It was established that the mass of 1000 seeds of the first tier has correlations with the number of seeds in a row and the number of rows (r = 0.32 and 0.39), which are attributed only to the group of noticeable ones. This indicates the possibility of combining in one plant a large number and size of seeds in the head. It was found that changes in the size and weight of the seeds in the head by zone occur in hybrids and lines gradually, while the variety shows only a slight decrease in the size and weight of the seeds in the third zone. The largest quantity and the best confectionary quality of seeds was provided by the Zaporizhzhya Confectionery variety. In hybrids, the output of seeds weighing 90–80 g from one head reached only 1000 pieces. The potential to increase the number of seeds in heads in hybrids is present, but the size of the seeds is critical. With the available average weight of 1000 seeds: 90 g in the best maternal line and 70 in the best paternal line, the hybrids only approached the 100 g mark.

Keywords: correlations; seed size; variety trait; line; hybrids; sunflower confectionary

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1 Introduction

Confectionery sunflower is a separate important direction of use and corresponding quality of the product. Seed size is one of the most important marketing components in the shelled sunflower confectionery market. The long and wide types of seeds are preferred for use as light snacks around the world. In Ukraine, a sunflower whose mass of 1000 seeds is 100 g or more is considered confectionery (Aliiev 2020). To achieve the required size and weight of seeds, as well as a higher protein content, cultivation takes place with a small number of plants per hectare – from 42 to 20 thousand plants (Kaya et al. 2007; Tigai and Tereshchenko 2017). A change in growing conditions, including available moisture, fertilizer, feeding area, can significantly affect the weight of 1000 seeds, protein content, seed size, and other characteristics (Feng et al. 2021; Mostafa and Afify 2022).

The second important component of obtaining confectionery seeds is the genotype, which provides the potential for large seed size and yield. For some time, only varieties were grown to obtain confectionary sunflower. Although in the oil field of sunflower cultivation, a full transition to hybrids took place more than 30 years ago. Confectionery varieties continue to be grown in larger volumes than hybrids. From an economic point of view, it should be expected that high-yielding confectionery hybrids will replace cultivars (Hladni et al. 2016). But why is this still not happening?

For confectionery varieties, a high negative correlation was established between the number of seeds and its weight of 1000 seeds, or size (Dyakov 1968). Forced self-pollination of varietal material showed the lowest efficiency of creating large-fruited breeding material based on varieties (Mamonov 2004). Taking into account the size of the seeds of parent plants involved in crossings is recognized as the best option for selection of confectionery material (Pérez-Vich et al. 2018; Tygai and Tereshchenko 2017), because high positive correlations of the weight of 1000 seeds with the size of the seeds were found (Bochkarev and Volgyn 2017).

It is known that the seeds in the head are located in a spiral and are formed from the outer edge of the head to the inner one. As a result of the study, it was found that in confectionery varieties, in contrast to oil varieties, the number of filled seeds in the head was significantly smaller (Vasyleva et al. 2012). This led scientists to the conclusion that selection for high fertility is actually selection for a smaller number of seeds in the head (correlation coefficient $r = -0.865$). Some results of hybrid selection confirm this fact, their weight of 1000 seeds is lower than the original varieties (Goncharov and Beresneva 2012).

A correlation analysis of 12 productivity components was conducted for confectionary sunflower hybrids. Yield and head diameter did not have a significant positive correlation. Seed width, seed length and yield had no significant negative correlation. Yield and the other 9 characteristics (plant height, stem diameter, number of seeds per plant, 100-seed weight, number of disc flowers per head, percentage of filled seeds, percentage of kernels in seeds, number of leaves, diameter of the head) had a strong positive correlation (Zhang et al. 2010).

In another study (Li et al. 2010), of the ovary percentage was significantly negatively correlated with seeds length, and 1000 seeds weight was highly significantly negatively correlated with adipose number and adipose kernel number. The diameter of the head was greater when the leaves were longer, but the percentage of set was lower when the achenes were longer.

The size of the flower also has its meaning. Corolla tube length has been shown to be inversely correlated with pollinator visitation (Portlas et al. 2018). Pollination problems in long-seeded confectioner's sunflower are thought to be caused by a correlation between seed and flower traits. Another study (Reinert et al. 2020) concluded that genetics is not a barrier to simultaneously improving seed length and pollinator-friendly flower traits. It is indicated that the selection of large seed size is possible without creating too long flowers. Classical studies on the establishment of genes that cause large seeds in sunflower are not yet known. Similarly, studies using molecular markers also do not have an answer about the number of components and genes of this trait. They include protein content (Ebrahimi et al. 2009). Other molecular studies have linked seed size to the B (plant branching), P (pistil armor) and Hyp (pistil hypoderm coloration) genes. It is possible that these relationships are partially or completely caused by the pleiotropic effects of B, P, and Hyp (Tang et al. 2006).

Summarizing all of the above, we can conclude that the sign of the size and weight of seeds still does not have a clear formula of its components. The development of this formula requires the involvement of a large number of component traits with a known nature of inheritance, the level of variation under the action of specific factors. Classical methods of working with the size of seeds on linear and hybrid material do not work: when maintaining the size, the quantity is lost, and this is already a loss of yield. In the studies described above, the regularities of the location of the seeds in the head and its fullness are not taken into account at the same time. In most studies, only two or three genotypes are studied at the same time, which does not allow understanding the true variability of the trait.

The purpose of our research was: – establishment of dependencies of seed characteristics in different parts of the head and other plant characteristics on the genetic material of lines, hybrids and varieties. – evaluation of breeding material for the combination of seed size and its yield.

2 Materials and methods

A collection of 23 parental lines, 10 hybrids and a variety was used as research material. On the basis of 9 lines with relatively large seeds, which could potentially create hybrids for confectionery use, 7 hybrid combinations were created. As relative standards, two large-seed hybrids Goodwin and Nasoloda of the V. Ya. Yuryev Plant Breeding Institute, which are included in the Register of Plant Varieties of Ukraine, were included in the study. All the listed names in the amount of 34 samples were included in the study during 2018–2020.

The selected samples were sown in plots with an area of 14 m^2 with a plant density of 40,000 plants per hectare. Such density in hybrids and varieties for the purpose of obtaining large seeds is not optimal. Producers are recommended 25–30 thousand plants per hectare, then it is possible to get the largest seeds. But we wanted to see in the study the result of the change in the size of the seeds in the head, which is best observed at a plant density of 40,000/ha.

Phenological observations and biometric measurements were carried out in the experiment. In particular: the height of the plants, the number of side head, the number of leaves on the plant, the diameter of the head. Three heads with optimal conditions and an average typical size were selected from the cultivated plots. Heads were measured in laboratory conditions, the diameter of the head and the number of rows seed of sunflowers along the outer edge of the head were counted. Each head was divided into three zones according to the intersection and location of the seed rows. The seeds were counted, weighed, and for each of the three tiers the following were determined: the total number of seeds, the number of seeds with a core, the weight of 1000 filled seeds, the length, width, and thickness of the seeds. Five seed measurements were taken from each head for each of the three tiers. The obtained data were calculated according to standard statistical methods: dispersion and correlation analysis in the Excel program (Schmuller 2021). The strength of the correlation was interpreted according to the Chaddock scale (Panchenko and Nemertsalov 2008).

3 Results and discussion

As a result of research, average indicators and errors were calculated for all measured characteristics. Table 1 presents several average characteristics that apply to the plant as a whole: plant height, number of leaves, side branches, head diameter, number of rows and seeds in a row, total number of seeds, number of filled seeds. As can be seen from the table, the studied samples had a high level of diversity. The biggest contrast with all lines and even hybrids was the sample of the Zaporizhzhia confectionery variety. All his indicators were at the highest level. The level of trait expression in lines and hybrids had significant differences. The variety and hybrids with the maternal line CX75A had the highest plant height. The smallest height up to a meter was observed in parent components 160B, 162B. Measurements of the diameter of the head showed that it was the largest except for the Zaporizhzhia confectionery variety (26.5 cm) in the maternal line KP11A and its hybrids (up to 17 cm). Accordingly, the smallest diameter of the head was observed in parental lines with the presence of lateral branching.

Table 1: Main characteristics of plants of parent lines, hybrids and Zaporizhzhia confectionery 2018–2020.

The name of the line, hybrid, variety	Plant height, cm	The number of leaves on a plant, pcs	Number of side branches, pcs	Head diameter, cm	Number of seeds in an arc, pcs	Number of arcs, pcs	Number of seeds in the head, pcs	The number of filled seeds in the head, pcs
КП11А	132.4 ± 4.44	28.6 ± 0.58	0	17.0 ± 2.08	20.0 ± 2.83	54.3 ± 0.82	1086.7 ± 156.42	472.7 ± 92.30
КП11Б	134.8 ± 7.02	34.8 ± 1.46	0	11.2 ± 0.20	22.0 ± 2.45	62.3 ± 4.98	1396.7 ± 272.85	265.7 ± 118.98
СХ75А	132.8 ± 3.95	31.0 ± 1.06	0	8.8 ± 1.08	18.7 ± 1.63	71.0 ± 4.90	1320.0 ± 112.25	458.3 ± 64.77
СХ75Ах162В	183.4 ± 5.21	29.0 ± 1.79	0	13.5 ± 0.35	21.3 ± 0.82	65.3 ± 4.32	1397.3 ± 135.92	950.7 ± 39.52
СХ75Ах340В	187.2 ± 7.02	36.4 ± 1.20	0	13.8 ± 1.43	19.3 ± 0.82	78.7 ± 4.30	1516.7 ± 191.09	802.0 ± 105.02
КП 11Ах178ав	167.8 ± 3.95	30.0 ± 0.45	0	15.0 ± 2.21	23.0 ± 1.87	66.7 ± 3.08	1542.3 ± 258.61	1082.0 ± 86.18
КП 11Ах164г	156.0 ± 3.98	26.4 ± 0.13	0	12.3 ± 1.08	17.3 ± 2.68	58.7 ± 5.76	996.3 ± 68.99	561.7 ± 73.66
КП 11Ах164вр1	140.4 ± 5.20	27.6 ± 3.26	0	13.3 ± 0.82	20.3 ± 1.08	51.0 ± 4.30	1037.7 ± 108.99	569.7 ± 46.19
КП 11А х 1676р1	158.6 ± 4.79	26.2 ± 2.33	0	17.5 ± 0.94	22.0 ± 2.45	66.3 ± 3.88	1436.7 ± 240.45	782.7 ± 139.85
КП 11А х 168Бн	155.0 ± 5.27	23.0 ± 1.12	0	14.3 ± 0.89	21.3 ± 0.82	55.0 ± 0.00	1173.3 ± 44.91	945.3 ± 91.85
160в	94.8 ± 7.69	22.4 ± 1.25	0	11.7 ± 0.20	18.0 ± 1.22	51.0 ± 3.74	922.0 ± 119.14	428.3 ± 33.26
340В	148.6 ± 4.16	21.8 ± 0.76	16.6 ± 0.58	6.7 ± 0.54	13.0 ± 0.71	50.0 ± 0.00	650.0 ± 35.36	279.0 ± 84.32
162В	95.2 ± 7.69	22.2 ± 0.76	0	10.5 ± 0.35	17.3 ± 2.04	55.0 ± 0.00	935.0 ± 102.90	120.3 ± 49.44
178ав	124.4 ± 0.58	29.2 ± 0.31	9.2 ± 0.31	8.5 ± 0.61	14.0 ± 1.87	51.0 ± 2.45	718.0 ± 120.46	455.7 ± 91.23
1686в	130.0 ± 1.12	24.4 ± 0.58	13.2 ± 0.31	8.0 ± 0.71	16.7 ± 2.27	36.3 ± 4.45	616.0 ± 233.59	298.3 ± 62.25
165Вр1	127.4 ± 1.92	33.2 ± 0.54	9.8 ± 0.54	5.0 ± 0.00	14.3 ± 2.16	44.3 ± 5.21	635.7 ± 131.50	220.0 ± 33.79
164г	147.4 ± 1.92	26.2 ± 0.54	10.4 ± 0.13	10.7 ± 0.54	15.7 ± 0.41	37.0 ± 3.67	577.7 ± 41.23	367.7 ± 22.76
174д	109.2 ± 11.05	26.6 ± 1.92	12.2 ± 4.56	6.0 ± 0.58	15.0 ± 1.69	40.0 ± 4.48	600.0 ± 185.02	217.0 ± 96.25
Zaporizhzhia confectionery	192.1 ± 1.35	31.0 ± 0.42	0	26.5 ± 1.77	32.7 ± 5.02	102.0 ± 8.60	3384.0 ± 744.01	1518.3 ± 217.23

The seeds in the head are arranged in an arc (spiral), such arcs have a different number of seeds and each arc starts from the outer edge of the head. We calculated the number of seeds in an arc (to the center of the head) and the number of arcs (the number of seeds in the first outer row). Unfortunately, the quality of repollination and weather conditions have a strong influence on seed germination and maturity. A study by Perrot et al. indicate that for sunflower, the relative contribution of self-pollination is 40 %, insect pollination 35 %, and wind pollination 20 % (Perrot et al. 2019).

To record the actual and potential number of seeds, the total number of seeds and the number of filled seeds were calculated separately. These seed counts showed that the lowest total number of seeds per head was observed between 577 and 718 seeds per main head in lines that had side heads. In parental lines without branching, there were more than 900 seeds per head, in maternal lines from 1086 to 1396 seeds, and in the best hybrids of the first generation up to 1542 seeds. A head of the Zaporizhzhia confectionery variety contains an incomparably larger number of seeds – 3384 pieces. The number of seeds in the arc of the lines with side head was not large, 13–15 pcs., while the single-head lines and hybrids had 17–22 pcs. Similarly, the number of arcs (36–50 pieces) was smaller in lines with side head, and in hybrids and maternal lines it reached 54–71 pieces. Moreover, the largest number of rows was observed in the CX75A line – 71 pcs., of course excluding the Zaporizhzhia confectionery variety, which had 102 pcs.

From the presented data, it can be seen: that the presence of side heads reduces the number of seeds in the central head, that the Zaporizhzhia Confectionery variety has two times more: the number of seeds in the head, the number of seeds in a row and the number of rows, the diameter of the head, the best hybrids and maternal lines. Maternal lines, in turn, have more seeds than paternal lines and even more than some hybrids. To confirm these hypotheses, a correlation analysis of all the studied features, including parameters (size, weight of 1000 seeds, number of seeds in each of the three selected tiers of the head) was conducted. Part of the results of the correlation analysis is presented in Table 2. Correlations with the traits of seeds of the second and third tiers are quite similar to the correlations of the same traits of the first tier, so they are not listed in the table.

A negative moderate correlation was inherent in the number of lateral heads on the plant in relation to the number, thickness of seeds, weight of 1000 seeds, diameter of the central head, number of seeds in an arc and number of arcs ($r = -0.5$ to -0.53). Other correlations of seed characteristics and the number of lateral heads are significant ($r = -0.38$ to -0.49). From these results, it is clear that the presence of branching reduces the size of the central head, the number of seeds and the weight of the seeds.

Table 2: Correlation coefficients of seed, head and plant traits of sunflower lines and hybrids in the experiment.

	The number of seeds in the row of the first tier	The number of seeds in the first tier	The number of filling seeds in the first tier	The number of filling seeds in the first tier	The mass of 1000 filled seeds of the first tier	The length of the seeds of the first tier	The thick-ness of the seeds of the first tier	The number of seeds in the head	The number of filled seeds in the head	Head diameter	Number of seeds in the row	The number of row in the head	Plant height	The number of leaves on a plant
The number of seeds in the first tier	0,88*	1.00												
The number of empty seeds in a tier	0.42*	0.48*	1.00											
The number of filling seeds in the first tier	0.73*	0.78*	−0.14	1.00										
The mass of 1000 filled seeds of the first tier	0.26*	0.32*	−0.02	0.44*	1.00									
The length of the seeds of the first tier	0.19	0.29*	−0.06*	0.32*	0.69*	1.00								
The width of the seeds of the first tier	0.20	0.32*	−0.08	0.39*	0.81*	0.79*	1.00							
The thickness of the seeds of the first tier	0.21	0.29*	0.03*	0.27*	0.75*	0.77*	0.87*	1.00						
The number of seeds in the head	0.83*	0.97*	0.58*	0.70*	0.37*	0.24	0.30*	0.28*	1.00					

Table 2: (continued)

	The number of seeds in the row of the first tier	The number of seeds in the first tier	The number of filling seeds in the first tier	The number of filling seeds in the first tier	The mass of 1000 filled seeds of the first tier	The length of the seeds of the first tier	The thickness of the seeds of the first tier	The number of seeds in the head	The number of filled seeds in the head	Head diameter	Number of seeds in the row	The number of row in the head	Plant height	The number of leaves on a plant
The number of filled seeds in the head	0.59*	0.64*	−0.04*	0.86*	0.53	0.26*	0.41*	0.23*	0.62*	1.00				
Head diameter	0.72*	0.82*	0.29*	0.74*	0.72	0.62	0.71*	0.69*	0.83*	0.66*	1.00			
Number of seeds in the row	0.92*	0.91*	0.51*	0.67*	0.32*	0.26*	0.29*	0.33*	0.91*	0.59*	0.79*	1.00		
The number of row in the head	0.60*	0.84*	0.62*	0.55*	0.39*	0.19	0.28*	0.22*	0.92*	0.55*	0.72*	0.71*	1.00	
Plant height	0.08	0.15	−0.32	0.46*	0.44*	0.07	0.32*	0.22*	0.21	0.68*	0.30*	0.21	0.17	1.00
The number of leaves on a plant	−0.15	−0.03	−0.03	−0.04	0.27*	0.18	0.18	0.10	0.03	0.10	0.00	0.01	0.10	0.43*
The number of lateral head on the plant	−0.47*	−0.48*	−0.39*	−0.36*	−0.52*	−0.49*	−0.47*	−0.52*	−0.50*	−0.38*	−0.51*	−0.53*	−0.51*	0.03

*Reliable with a probability of 0.95. The color of the cell indicates the strength of the connection on the Chaddock scale: from dark red (indicates a high positive correlation) to dark green (indicates a moderate negative correlation).

The size of the seed is mainly in thickness and less in length. It should be noted that in our study we used lines with branching caused by one recessive b1 gene, which is usually used in breeding (Rojas-Barros et al. 2008). In the research of the staff of the IOC of the National Academy of Sciences using the same branching, it was shown that single-head parent lines are more productive in terms of the number of flowers and seeds than lines with branching (Shcherban 1999). Regarding the correlation of the mass of 1000 seeds with the presence of branching, all breeders understand that there are significantly fewer seeds on the side heads than on the main one, but this is not discussed in modern research. At that time, a number of similar patterns were found on grain crops, in particular rice and wheat. Thus, the weight of 1000 rice seeds is greater on the central panicle (Kim et al. 2005).

In wheat and rice, the important role of BR TaD11 (brasnosteroids) biosynthetic genes, which affect grain size and root length at the same time, has been proven (Xu et al. 2022). DELLA genes are probably homologous to such a gene in sunflower, which cause the manifestation of sunflower stunting associated with the shortening of internodes and roots (Best et al. 2016; Ramos et al. 2013). On the lines carrying these genes, rather small seeds are observed. When studying analogues of lines with and without dominant stunting genes, a negative effect of this gene on the weight of 1000 seeds was established (Vedmedeva and Makhova 2019). In our study (Table 2), the height of the plant had a moderate positive correlation with the number of filled seeds and a noticeable positive correlation with the characteristics of seed mass, width, seed thickness, head diameter. Among the studied lines, none had dominant Dw stunting genes, so this relationship is a positive influence of growing conditions on the plant as a whole and on seed size and weight.

Very high and high positive correlation values from $r = 0.72$ to $r = 0.97$ were observed between similar in content features of the whole head and its part – the first tier: the number of seeds, the number of filled seeds, the diameter of the head, the number of rows and the number of seeds in row There were also high coefficients between the weight of a thousand seeds and all three measurements of seeds: length, width, thickness. We have already reported on this regularity in previous studies (Vedmedeva and Nosal 2020).

A high positive correlation of $r = 0.71$ was also revealed between the number of rows in the head and the number of seeds in the row. This relationship shows the presence of regularities of laying and the formation of an inflorescence. There are known studies on plants of another type of complex-flowered plant – gerberas, in which the number of flowers in inflorescences is stable. The authors identified a single gene that controls the fate of the flower meristem and inflorescence in the plant. They believe that an integrative role in reproductive meristem development may be common to all flowering plants (Teeri et al. 2006).

In our studies, the mass of 1000 seeds of the first row has high positive correlations with seed width (r = 0.81), thickness (r = 0.75), head diameter (r = 0.72) and moderate correlations with seed length (r = 0.69) and the number of filled seeds (r = 0.53) (Table 2). While the correlation between the signs of the number of seeds in the head and the weight of 1000 seeds can be classified as significant (r = 0.37). From this follows a rather important idea about the possibility of combining in one plant a large number and size of seeds in a head. Accordingly, these two signs ensure the yield of sunflower. At least a high positive correlation of the weight of 1000 seeds and yield has already been proven (Marinkovic 1992).

However, the seeds in the head are not of the same size and weight (Mamonov 2004). A change in the number of flowers and the fertility rate of the central part of the head is very often observed (Villalobos et al. 1994), when the center of the head does not have complete seeds. Therefore, the head was divided into three zones and the seeds were studied separately. The first zone is the outer one, which grows the longest and has the largest seeds. The second zone is the middle zone, in which most of the seeds are already formed in size. The third zone is the inner one, where there are fewer seeds and there are many incomplete ones. Each zone includes 5–10 seeds in an arc. The number of seeds was determined as approximately one-third of the set flowers in the arc. Significant differences between individual samples were observed for each of the tiers. For example, among parental lines, the mass of 1000 seeds of the first tier ranged from 28 g in line 168bv to 86 g in line 162p1. Larger seed sizes and weights were observed in hybrids. The weight of 1000 seeds of the first tier is from 72 to 114 g. Data separately for hybrids, paternal and maternal lines were averaged and shown in Figures 1–4.

It can be seen from Figure 1 that in the parental lines, unlike the maternal lines, there is a significant decrease in the size of the seeds up to the third tier. In the work on the Donsky variety, large-seed varietal material had a seed length of up to 18.5 mm at a stand density of 30,000 plants/ha (Gorbachenko 1995). In our conditions, the Zaporizhzhia Confectionery variety had shorter seeds, but differed significantly from the lines and had the largest seed sizes. Figure 2 shows that the seed width is a stable indicator for the Zaporizhzhia confectionery variety and for hybrids. Paternal and maternal lines have a significant reduction in seed width. From this it can be concluded that greater changes in seeds by location are observed in lines than in hybrids.

Figure 3 shows a decrease in the third tier of seed thickness in all samples. Moreover, for example, in maternal lines, a significant decrease in thickness was observed even on the second tier. It is known how scientists calculated the output of the corresponding fractions of seeds from the full harvest of heads (Dmitrievska 2005). In particular, it was established experimentally on the Postolyanskyi variety that the fraction 2.5–3.0 had a decrease in sowing qualities. It accounted for 6.7 % of

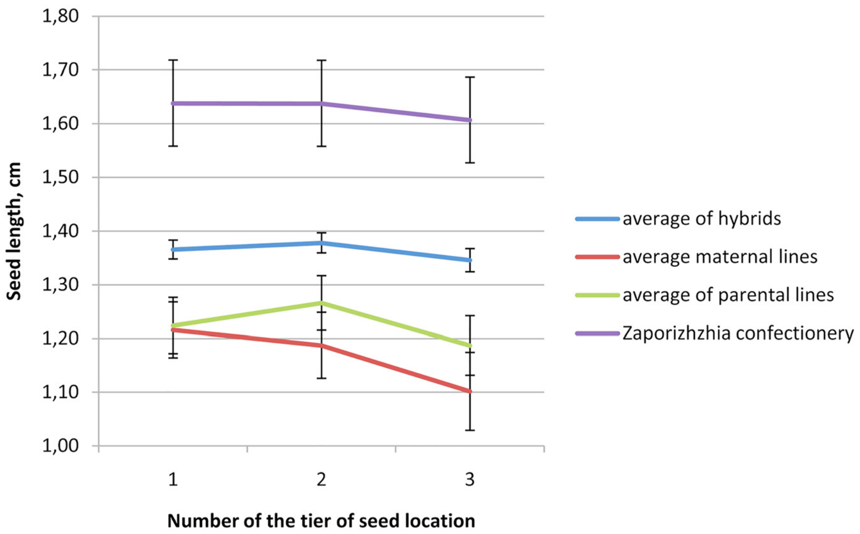

Figure 1: The length of the seed by tiers of location in the studied sunflower material.

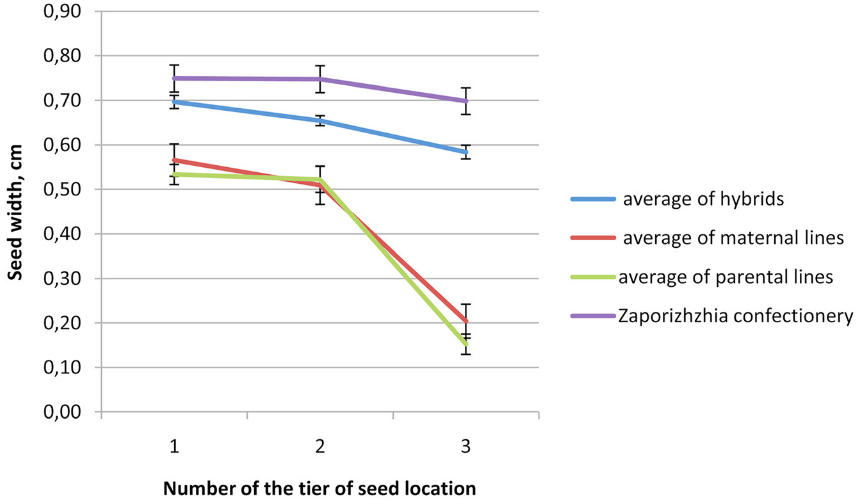

Figure 2: The width of the seed by tiers of location in the studied sunflower material.

all the seeds in the head in quantitative terms, and 6.7 % by weight. In our experiment, neither the variety nor the hybrids had such small seed thickness (less than 2.5 mm). This was the size of the parent components.

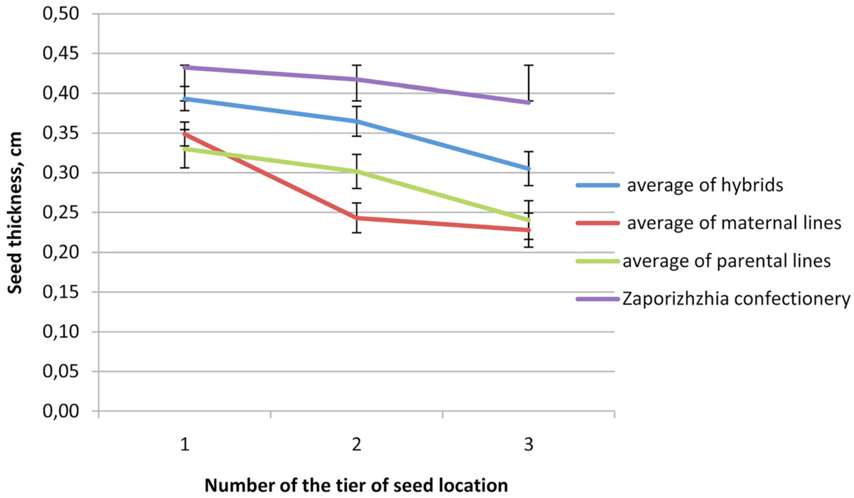

Figure 3: The thickness of the seed by tiers of location in the studied sunflower material.

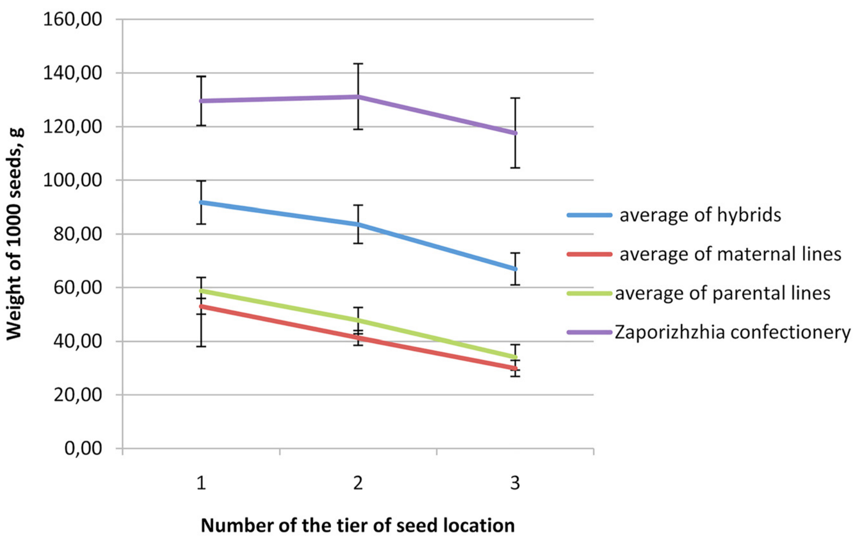

Figure 4: Mass of 1000 seeds by location tiers in the studied sunflower material.

Most lines have significantly less seed thickness than the proposed fraction of 2.5–3.0. From this it becomes clear that in order to establish regularities in the size and weight of the seeds in the head, it is necessary to have zones. At least three as in our study, which allowed us to see the differences between maternal and paternal lines.

The mass of 1000 seeds, a complex indicator of seed size, is presented in Figure 4. The graph shows that the Zaporizhzhia confectionery variety significantly exceeds hybrids and even more so lines in terms of this indicator. However, the variety has an almost constant weight of 1000 seeds in two tiers, and only in the center of the head are the seeds less in weight. While in hybrids, there is a decrease in the weight of 1000 seeds in the second tier as well.

In the lines, all three tiers form a straight line, which indicates a constant decrease in the mass of 1000 seeds. The decrease in 1000-seed weight is gradual, but the third inner head tier in most hybrids and lines has a significant decrease in 1000-seed weight. Therefore, to evaluate the potential of lines and hybrids, we constructed a diagram in Figure 5. It took into account all sunflower genotypes and their three parameters: the average number of seeds planted in a head, the average number of filled seeds available in a head, and the average weight of 10,000 seeds. The weight parameter of 1000 seeds has been replaced by 10,000 for better visualization of the selection.

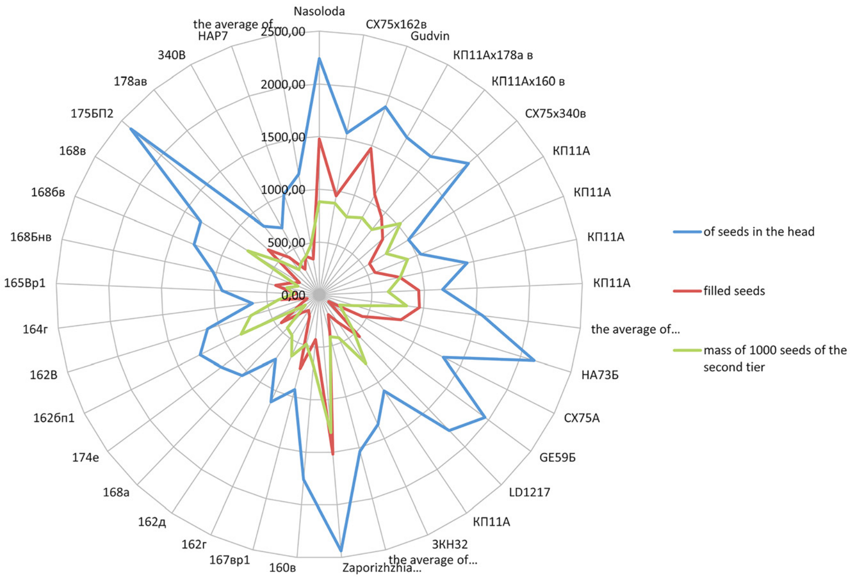

Figure 5: Map of the average indicators of availability and seed size of the studied lines, hybrids and varieties.

It can be seen from the figure that the best combination of these three indicators has the Zaporizhzhia confectionery variety. The hybrids Nasoloda, Goodwin, Сх75х162в, КП11А х 178ав, СХ75х340в, КП11А х 167бр2 had a high seed head yield of about 1000 seeds weighing 90–80 g. The diagram shows that the potential to increase the number of head seeds in hybrids is present, but seed size is critical. Among the studied, there are lines with a fairly high potential for forming a mass of 1000 seeds of about 70 g, and low binding, or fullness of the head: 168в, 162бп1, КП11А, 162г. They will require further improvement in the level of self-pollination and further seed growth, and involvement in hybrid combinations.

The results of research on breeding material show a real advantage in the yield of large seeds of the sunflower variety over the created hybrids. An analysis of historical events in the selection of oilseed sunflower shows that when transitioning from varietal to hybrid and linear sunflower and selection for high oil content, there was a decrease in seed size and an increase in its number (Tang et al. 2006). A high positive correlation of the weight of 1000 seeds and yield is known (Marinkovic 1992). However, the sunflower head has seeds of different sizes and weights (Mamonov 2004). Therefore, our proposed approach of dividing the head into zones and studying the characteristics of the seeds in the head according to their location will help in the invention of new methods of evaluation and selection of confectionery sunflower. It will make it possible to invent those genetic components of traits that can be clearly separated from the influence of environmental conditions and used in breeding.

Perhaps these components have something in common with genetic factors discovered in other crops: panicle and spike size in rice and wheat (Okada et al. 2018; Xie et al. 2018), reproductive meristem development in gerbera and Arabidopsis (Teeri et al. 2006). However, solving modern practical tasks of sunflower selection (primarily for confectionery) requires the invention of characteristics for selection that cannot be directly used from other cultures. The conducted research on sunflower allows us to focus in the future on the following aspects: – dividing the head into three zones and evaluating each one separately shows the presence of incomplete seeds in the center, and the possible percentage of large seeds leaving the head; – the use of seed length, especially in the first zone, shows the presence of seed size even in lines with branching, or in unfavorable growing conditions.

4 Conclusions

As a result of the conducted research, moderate negative correlations of the sign of the number of side heads (branching) in sunflower lines with the majority of seed indicators in the central head (r = –0.5 to –0.53) were established. In particular, the mass of 1000 seeds, the number of rows, seeds in a row, the total number of seeds and the diameter of the head.

High correlation values from r = 0.72 to r = 0.97 were confirmed between the characteristics of the whole head and its part – the first tier: the number of seeds, the number of filled seeds, the diameter of the head, the number of rows and the number of seeds in a row. Also, there were high coefficients between the mass of one thousand seeds and the size of the seeds.

The dependence of the number of seeds in the head on its size was confirmed (r = 0.83). In particular, we obtained a high positive correlation between the signs of the number of rows in the head and the number of seeds in the row with the size of the head (0.71 and 0.72). It was established that the mass of 1000 seeds of the first tier has correlations with the number of seeds in a row and the number of rows (r = 0.32 and 0.39), which are attributed only to the group of noticeable ones. This indicates the possibility of combining in one plant a large number and size of seeds in the head.

The need to divide the head into zones when studying seeds is shown, which gives more opportunities to evaluate lines and hybrids by size, weight, number of seeds of appropriate quality.

From the studied material, the Zaporizhzhia confectionery variety is the undisputed leader by all indicators, the size and weight of seeds in its heads are significantly reduced only in the third (inner) zone of the head. Our maternal lines have more seeds than the paternal lines and even more than some of the hybrids.

The best combination of the total number, the number of filled seeds and its mass of 1000 seeds has the Zaporizhzhia confectionery variety. The hybrids Nasoloda, Goodwin, Сх75х162в, КП11Ах178ав, СХ75х340в, КП11Ах167бр2 had a high seed head yield of about 1000 seeds weighing 90–80 g.

The potential to increase the number of seed heads in hybrids is present, but seed size is critical. Among the studied lines, there are lines with a fairly high potential for the formation of a mass of 1000 seeds of about 70 g, and low binding, or fullness of the head: 168в, 162бп1, КП11А, 162г. They need further improvement of the level of self-pollination and involvement in hybrid combinations.

Research ethics: The local Institutional Review Board deemed the study exempt from review.

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