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Selection value of initial material according to the main biochemical parameters of grain in new maize hybrids creation

R.O. Spriazhka[1,*], V.L. Zhemoida[1], O.S. Makarchuk[1], Y.M. Dmytrenko[1] and V.V. Bahatchenko[2]

[1]National University of Life and Environmental Sciences of Ukraine, Agrobiological Faculty, Department of Genetics, Plant Breeding and Seed Production them Prof. M. O. Zelensky, 13 Heroiv Oborony Street, UA03041 Kyiv, Ukraine
[2]Agrofirma Kolos, 18a Vatutina Street, UA09051 Pustovarivka, Skvyrskyi district, Kyiv region, Ukraine
[*]Correspondence: roman.spriazhka@nubip.edu.ua

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Abstract. Increasing demand for corn grain with improved quality indicators provides grounds for creating new breeding samples that can meet the requirements of society. To achieve this goal, the breeding program included inbred lines VK13, VK69, AE801, and AE392 - sources of mutations in the gene for endosperm structure *waxy* and *ae*, respectively. The article presents experimental data on the study of corn hybrids created by crossing with these sources of gene mutations and is characterized by a high content of protein, starch, and oil in the grain, as well as yield. According to the results of laboratory and field research, hybrid combinations with high protein content in grain were identified - 13.07%; starch - 72.6%; oils - 5.83%. In field conditions, the highest yield was 9.37 t ha^{-1}. Further research will determine the nature of the inheritance of these traits, and suggest ways of breeding work to improve grain quality.

Key words: breeding, hybrid, corn, protein, starch.

INTRODUCTION

In maize hybrid development, it is essential to know the parent's performance per se in different environments as well as the genetic base in populations to facilitate the selection of superior lines (Gayosso-Barragán et al., 2020).

The quality of maize grain is determined by biochemical parameters, such as the content of proteins, starch, and oil. The most effective and efficient method of improvement is breeding (Kuzmishina et al., 2014). Mutations of endosperm structure genes that significantly change the biochemical composition of grain are successfully used to create maize hybrids for specific purposes. A lot of research confirmed the effectiveness of using mutations of endosperm structure genes and their combinations to optimize the biochemical composition of grain (Boyer & Hannah, 2001).

The main component of maize grain is starch, which makes up about 70% of the total weight of the grain. It is represented by amylose and amylopectin. The high protein content of maize grain is usually positively correlated with the oil content. Maize grain, in comparison with other cereals, excluding oats, is characterized by the highest oil content (3.5–7%). The fats in the grain are unevenly distributed. The largest number (up to 60%) is concentrated in the embryo and only 0.61–0.73% is in the endosperm (Shorohov, 2007).

The creation of maize hybrids with improved grain biochemical composition depends on the availability of a reliable source material for breeding (Zemoida et al., 2019; Vasylenko et al., 2021). It must have a high genetically determined level of grain quality traits, stably reproduce this level in different climatic conditions of cultivation and be combined with productivity and other valuable economic traits (Silenko, 2011).

It is known that maize grain endosperm contains a complex mixture of starch granules and protein bodies. The physical structure of endosperm depends on the type of interaction between these compounds, and reserve proteins play an important role in the physical structure of mature grain (Pereira et al., 2008; Shcherbakov et al., 2017; Mazurenko et al., 2020). About 7.0–11.2% of protein accumulates in the endosperm, which is 81% of the grain mass, and 14.0–26.0% of the protein in the embryo, which is 11.7% of the grain mass. The concentration of protein in the aleurone layer is the highest, in its cells found up to 36% of protein to dry weight of endosperm (Wolf et al., 1972; Watson, 2003).

In maize grain with a floury texture, starch granules and protein bodies are located in the endosperm disorganized. In vitreous grains, the location of starch granules is more organized, and the intergranular spaces are perfectly filled. Reserve proteins are usually responsible for the relationship between starch grains and endosperm matrix proteins, thus affecting grain hardness (Gibbon & Larkins, 2005). Waxy maize, also known as sticky maize, has high economic, nutritional, and processing value. In recent decades, many adapted maize inbred lines have been developed for hybrid seed production by different selection methods. Because of the popularity of glutinous maize, waxy maize lines are frequently selected by maize breeders. An abundance of waxy maize germplasm has been obtained through decades of waxy maize breeding (Luo et al., 2020).

Maize oil is characterized by high energy content. The energy value of 100 g of maize oil is about 884 kcal. Good quality cooking oil is usually associated with an increased proportion of unsaturated and saturated fatty acids. Maize oil is low in saturated fatty acids and contains an average of 11% palmitic acid and 2% stearic acid, compared to relatively high levels of polyunsaturated fatty acids such as linoleic acid. Maize oil is relatively stable because it contains only a small amount of linolenic acid (0.7%) and has a high level of natural antioxidants (Val, 2009). The caloric content of the oil is 2.25 times higher than that of starch, and research on livestock feeding has shown a higher rate of weight gain per unit of feed for high-oil than for ordinary Maize (Lambert et al., 2004).

The current rapid expansion of the human population on earth, particularly in the less developed countries, raises the possibility of widespread, serious malnutrition and starvation for many unless agricultural technology can intervene with appropriate answers to these problems. Plant breeders have been charged with developing varieties with high yields and improved quality of grain (Prasanna et al., 2001). Therefore, substituting the normal maize for high-quality maize would substantially reduce the malnutrition problems of resource-poor people depending on maize as a staple food (Gemechu et al., 2016).

With a hybrid modeling, it is difficult to predict how one or another valuable economic trait will manifest itself in different combinations and growing conditions. As a rule, most morphological and adaptive traits have a complex nature of inheritance, which is polygenic. Therefore, the strategy of modern selection is an in-depth study of these traits, as a result of which it will be possible to control the processes of their production (Zhemoyda et al., 2019).

The research aimed to determine the suitability of inbred lines - sources of mutations in the gene of endosperm structure waxy and ae for the creation of new breeding samples of maize with high content of protein, starch, oil, and high yields.

MATERIALS AND METHODS

The purpose and objectives of the experiment are selection of source material (inbred lines) of maize for inclusion in crosses with sources of high protein, high starch, and oil content, followed by obtaining high-heterosis hybrids with high yields.

Field research was conducted during 2020–2021 in the research fields of the laboratory of the Department of Genetics, Breeding and Seed Production. prof. M. O. Zelenskyi NULES of Ukraine of a separate subdivision of NULES of Ukraine ‘Agronomic Research Station’, located in Bila Tserkva district of Kyiv region. The soil of the experimental site is typical, low-humus chernozem. Total atmospheric precipitation during the growing season between 29/04 and 10/10 was 301 mm in the 2020, and only 173 mm between 12/04 and 8/10 in 2021 growing season. There was much less atmospheric precipitation, but it fell on the main critical phases of the maize vegetation, which contributed to the normal maize cultivation (Fig. 1). Groundwater is at a depth of 1.5–2 m, this is the reason for additional irrigation was not carried out. Fertilizers and herbicides were not applied at the experimental sites. The predecessor of both years was winter wheat.

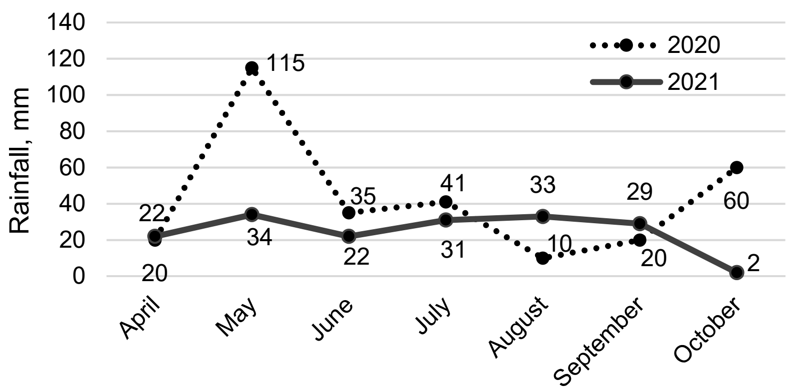

Figure 1. Average amount of atmospheric precipitation per month, mm (2020–2021).

The accounting area for each analyzing sample was a double row of a 7 m long plot, spacing between from row to row was 70 cm and from plant to plant was 17 cm. (Dospehov, 2012). The research plots were located according to the RCBD design in triple duplication.

Research material: 65 experimental maize hybrids created as a result of test crosses; testers VK13, VK69 (sources of mutation of the endosperm structure gene - *waxy*), AE801, AE392 (sources of mutation of the endosperm structure gene - *ae*); inbred lines - source material of researching hybrids.

Evaluation of experimental maize hybrids in terms of protein, starch, oil, and yield was performed according to the method of the qualifying examination of plant varieties on suitability for distribution in Ukraine (Tkachyk, 2017). FOSS 'Infratec 1241 Grain Analyzer' was used to determine the main biochemical indicators of maize grain quality. The principle of device operation is based on infrared spectrophotometry. Uncrushed and unprocessed grain was used for analysis (Tkachyk, 2017). The content of protein, starch, and oil is shown as a percentage of grain dry matter.

To determine the biochemical parameters, five sources were randomly selected from each plot. After drying in the laboratory, the cobs were threshed by hand. The obtained grain was cleaned of impurities on sieves, after which the analysis was performed.

The division of all hybrids into groups according to the content of protein, starch, and oil in the grain was performed according to the description reference book for the *Zea mays* L species. (Kyrychenko et al., 2009).

To carry out mathematical and statistical data processing, the studied hybrids were compared with each other in four groups formed according to their maternal form - the tester. The group with the VK13 tester included 24 hybrids; with tester VK69 - 19 hybrids; with tester AE801 - 14; with AE392 tester - 8 hybrids. The conditional standard was the average value of the indicator (protein, starch, oil, and yield) within the group.

Heterosis was estimated based on mid-parent heterosis (MPH) using the following formulae:

MPH (%) = 100 × (F1 – MP)/MP

To determine the significance of the difference between the means, the criterion of least significant difference (LSD) was used, which shows the marginal deviation for the difference of the sample means. If the actual difference is greater than the *LSD* it is significant.

Statistical data processing was performed using Microsoft Excel 2016 in combination with XLSTAT. The error of the results of statistical analysis is $P < 0.05$.

RESULTS AND DISCUSSION

The maternal components for experimental maize hybrids creation were four inbred lines: VK13 and VK69 - sources of mutations in the gene structure of the *waxy* endosperm structure; lines AE392 and AE801 are sources of mutations in the gene of the endosperm structure *ae* (Shiyanova et al., 2015). These inbred lines were characterized by high protein, starch, and oil content (Zhemoida et al., 2020) (Table 1).

According to the results of laboratory analyses of the main biochemical components conteined in the grain, all the studied experimental hybrids were grouped by the percentage of protein, starch, and oil.

Table 1. Content of the main components of quality in a grain of maize inbred lines - source material of analyzing hybrids (2020–2021)

Inbred line name	Nutrient content, %					
	Protein		Starch		Oil	
	2020	2021	2020	2021	2020	2021
	Maternal form					
AE801	13.8 ± 0.5	13.7 ± 0.3	66.8 ± 0.7	66.2 ± 1.1	5.9 ± 0.2	5.9 ± 0.1
AE392	12.0 ± 0.3	12.5 ± 0.2	70.3 ± 0.8	71.9 ± 0.6	4.4 ± 0.9	4.6 ± 0.1
VK69	10.8 ± 0.2	11.5 ± 0.3	70.7 ± 0.7	72.1 ± 0.9	5.3 ± 0.1	5.5 ± 0.1
VK13	12.2 ± 0.2	12.2 ± 0.5	70.9 ± 0.6	71.9 ± 0.8	4.2 ± 0.1	4.1 ± 0.1
	Paternal form					
CO255	12.9 ± 0.4	12.6 ± 0.3	67.9 ± 0.7	67.4 ± 0.7	4.0 ± 0.0	3.9 ± 0.1
FV243	11.8 ± 0.4	11.3 ± 0.2	69.8 ± 0.7	71.8 ± 0.9	4.2 ± 0.1	4.2 ± 0.1
G255	13.2 ± 0.8	12.8 ± 0.5	68.2 ± 0.7	70.3 ± 0.6	4.2 ± 0.1	4.1 ± 0.1
Q170	12.0 ± 0.2	11.5 ± 0.2	71.4 ± 0.8	71.7 ± 1.1	3.9 ± 0.1	4.1 ± 0.1
HLG1203	11.4 ± 0.2	11.5 ± 0.3	70.4 ± 0.6	70.5 ± 0.9	3.9 ± 0.1	3.9 ± 0.1
UHK678	10.5 ± 0.2	10.5 ± 0.3	68.0 ± 0.5	68.8 ± 0.8	4.2 ± 0.1	4.1 ± 0.1
UHK686	12.2 ± 0.5	11.8 ± 0.4	71.7 ± 0.6	70.2 ± 0.7	3.7 ± 0.1	3.5 ± 0.1
AK157	11.1 ± 0.3	10.6 ± 0.1	70.8 ± 1.1	69.9 ± 0.6	4.3 ± 0.1	4.3 ± 0.1
AK159	10.0 ± 0.3	9.8 ± 0.3	70.0 ± 1.0	69.6 ± 0.6	4.4 ± 0.1	4.2 ± 0.2
VK19	12.0 ± 0.2	11.5 ± 0.2	64.8 ± 0.5	69.8 ± 0.7	5.3 ± 0.8	4.9 ± 0.1
VK32	12.3 ± 0.4	12.0 ± 0.3	69.5 ± 0.8	72.3 ± 0.8	3.7 ± 0.1	3.6 ± 0.1
VK37	11.5 ± 0.3	11.7 ± 0.3	70.8 ± 0.9	69.7 ± 0.9	3.9 ± 0.1	3.8 ± 0.1
AE746	13.6 ± 0.3	12.9 ± 0.3	68.7 ± 0.9	65.5 ± 0.4	5.6 ± 0.2	5.4 ± 0.2
AE800	10.4 ± 0.4	10.8 ± 0.3	72.1 ± 0.6	70.1 ± 0.8	4.9 ± 0.2	4.9 ± 0.1
Conditional standard	11.9	11.7	69.6	69.6	4.5	4.4
$LSD_{0.05}$	0.94	0.73	1.61	1.30	0.22	0.24

There were four groups in terms of protein content: 18 samples were included in the group with less than 9.0% protein content; the group with a protein content of 9.1–10.0% - 24 samples; the group with a protein content of 10.1–12.0% - 21 samples and the group with a high protein content of 12.1–15.0% - 2 samples (Fig. 2).

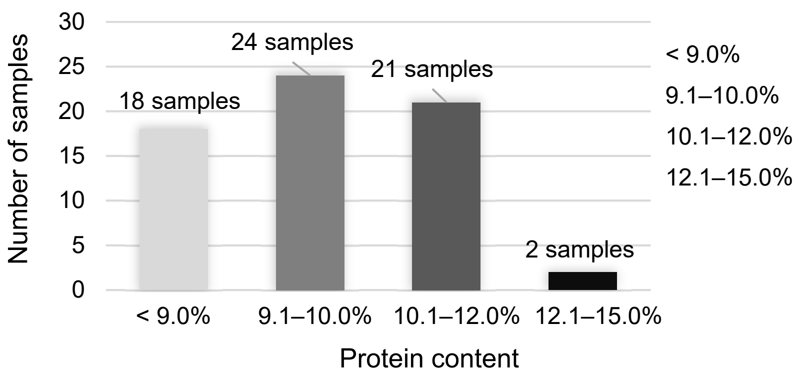

Figure 2. Distribution of hybrids by protein percentage.

According to the starch content, 65 experimental hybrids were divided into III groups: Group I with a starch content of 61–65%, which included 3 samples; Group II with a starch content of 66–70% - 45 samples and Group III with a starch content > 70% - 17 samples (Fig. 3).

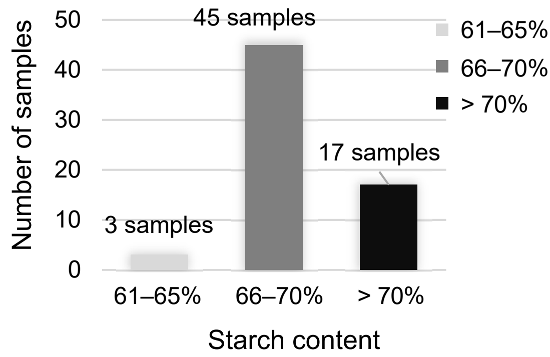

Figure 3. Distribution of hybrids by starch percentage.

According to the oil content, III groups were also formed: with a content of 2.6–3.8% - 7 samples; with a content of 3.9–5.0% - 52 samples, and a group with an oil content of 5.1–7.0% - 6 samples (Fig. 4).

According to analyzing results of the group of experimental hybrids using the maternal form VK13, it was found that the average protein content for 2 years varied between 7.97–13.07%, with standard deviation (*s*) 0.547, starch - 65.9–72.6% ($s = 0.8519$), oil - 3.9–5.27% ($s = 0.2393$).

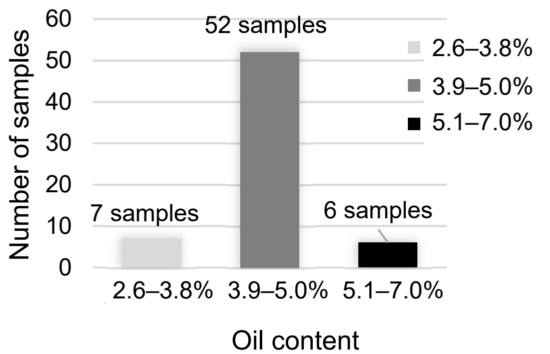

Figure 4. Distribution of hybrids by oil percentage.

Significantly average high protein content was found in hybrids VK13xCO255 (13.07%) and VK13xVK37 (12.60%). A very high content of starch in grain was observed in hybrids: VK13xUHK678 (72.60%) and VK13xUHK686 (72.57%). High oil content was formed by hybrids VK13xVK37 (5.27%) and VK13xUHK686 (5.07%).

In 2020 hybrid VK13xVK37 were characterized by a significant positive degree of MPH in terms of protein and oil content; VK13xUHK686 - by oil content; VK13xUHK678 - starch content. In 2021, a positive manifestation of MPH was found in hybrids VK13xVK37 and VK13xUHK678 in oil content (Table 2).

Average protein content in the grain over the years of research of the analyzed hybrids group, the maternal form of which was the inbred line VK69, varied between 8.03–9.83% ($s = 0.5026$), starch - 67.50–72.80% ($s = 0.9322$), oil - 3.67–5.27% ($s = 0.3293$).

According to biochemical indicators, high, significantly higher than the conditional standard, the oil content in the grain formed by a hybrid VK69xVK13 (5.27%), and very high starch content was characterized by a hybrid VK69xFV243 (72.80%).

Table 2. Description of hybrids with maternal form VK13 (2020–2021)

Hybrid formula	Content in the grain, % / MPH, %			Yield, t ha^{-1}
	Protein	Starch	Oil	
	2020			
VK13xCO255	13.1 ± 0.2 / 7.57	68.2 ± 0.4 / –0.39	4.5 ± 0.1 / 9.40	6.85
VK13xVK37	12.5 ± 0.2 / 10.29	67.3 ± 0.8 / –6.42	5.3 ± 0.1 / 30.44	5.79
VK13xUHK678	9.2 ± 0.2 / –18.56	73.1 ± 0.8 / 5.17	4.7 ± 0.1 / 10.38	4.64
VK13xUHK686	8.3 ± 0.2 / –32.18	73.1 ± 0.8 / 2.43	5.0 ± 0.1 / 25.87	8.74
VK13xAK159	10.4 ± 0.2 / –6.76	68.5 ± 0.8 / –1.35	4.2 ± 0.1 / –3.00	5.41
VK13xFV243	9.6 ± 0.2 / –20.40	67.4 ± 0.8 / –4.23	4.7 ± 0.1 / 11.82	6.48
VK13xAE746	10.8 ± 0.3 / –16.68	64.9 ± 0.6 / –7.09	4.7 ± 0.2 / –5.47	4.39
VK13xVK19	11.2 ± 0.2 / –7.94	66.9 ± 0.6 / –4.43	4.9 ± 0.2 / 3.35	4.01
Conditional standard	10.4	69.1	4.5	5.77
$LSD_{0.05}$	0.68	4.62	0.34	0.42
	2021			
VK13xCO255	13.0 ± 0.4 / 1.25	66.9 ± 0.6 / –5.43	4.4 ± 0.1 / 10.00	6.45
VK13xVK37	12.7 ± 0.3 / 0.77	69.5 ± 0.8 / –0.39	5.2 ± 0.2 / 33.22	4.47
VK13xUHK678	10.2 ± 0.3 / –10.76	72.1 ± 0.7 / 2.52	4.5 ± 0.2 / 11.06	5.70
VK13xUHK686	7.6 ± 0.2 / –36.39	72.1 ± 0.9 / 1.46	5.1 ± 0.1 / 35.36	6.52
VK13xAK159	9.7 ± 0.3 / –11.91	67.2 ± 0.5 / –6.38	4.3 ± 0.1 / 4.84	6.79
VK13xFV243	9.5 ± 0.3 / –18.92	70.3 ± 0.4 / –2.08	4.6 ± 0.2 / 11.90	8.52
VK13xAE746	10.6 ± 0.2 / –15.65	66.9 ± 0.4 / –2.56	4.6 ± 0.1 / –2.55	4.97
VK13xVK19	11.1 ± 0.3 / –6.10	68.3 ± 0.7 / 3.68	5.0 ± 0.2 / 10.84	4.87
Conditional standard	10.3	69.4	4.5	6.03
$LSD_{0.05}$	0.70	4.37	0.29	0.40

In 2020, in terms of starch content in grain, the highest manifestation of MPH was found in hybrid VK69xAK159, in terms of oil content - hybrid VK69xVK13. In 2021, a positive manifestation of MPH in terms of starch content in grain was found in hybrid VK69xVK19, and oil content - in hybrid VK69xVK13 (Table 3).

According to the 2 years average results, analyzed grain quality of hybrids, the maternal form of which was the inbred line AE801, it was found that variation in the percentage of protein was 8.7–11.27% (s = 0.5592), starch - 65.0–70.83% (s = 0.9711), oil - 3.67–5.13% (s = 0.2786).

Table 3. Description of hybrids with maternal form VK69 (2020–2021)

Hybrid formula	Content in the grain, % / MPH, %			Yield, t ha^{-1}
	Protein	Starch	Oil	
	2020			
VK69xVK13	9.4 ± 0.2 / –20.90	69.4 ± 0.3 / –2.00	5.3 ± 0.2 / 10.19	6.06
VK69xCO255	9.4 ± 0.2 / –20.75	70.4 ± 0.5 / 1.54	4.3 ± 0.1 / –8.16	6.24
VK69xG255	9.7 ± 0.3 / –19.76	70.0 ± 0.4 / 1.49	4.3 ± 0.1 / –9.73	10.57
VK69xUHK686	7.8 ± 0.3 / –32.57	70.9 ± 0.5 / –0.34	3.6 ± 0.1 / –21.06	8.20
VK69xVK19	9.8 ± 0.3 / –14.23	69.9 ± 0.6 / 0.31	4.3 ± 0.1 / –18.09	5.56
VK69xAE746	9.1 ± 0.4 / –25.42	66.3 ± 0.9 / –4.96	4.6 ± 0.1 / –16.15	6.19
VK69xFV243	8.4 ± 0.2 / –26.19	72.4 ± 0.6 / 2.17	4.6 ± 0.1 / –3.81	4.39
VK69xAK159	8.6 ± 0.2 / –17.92	72.3 ± 0.3 / 2.70	3.6 ± 0.2 / –25.78	4.97
Conditional standard	8.8	69.7	4.3	6.13
$LSD_{0.05}$	0.75	5.41	0.30	0.51

	2021			
VK69xVK13	9.9 ± 0.2 / –15.28	70.6 ± 0.4 / –1.85	5.3 ± 0.1 / 10.40	4.91
VK69xCO255	8.9 ± 0.5 / –25.88	71.4 ± 0.8 / 2.33	4.3 ± 0.1 / –8.86	5.97
VK69xG255	10.0 ± 0.2 / –17.73	68.5 ± 0.4 / –4.49	4.1 ± 0.1 / –15.25	8.18
VK69xUHK686	8.3 ± 0.1 / –29.06	68.5 ± 0.4 / –3.63	3.8 ± 0.1 / –16.34	6.08
VK69xVK19	9.3 ± 0.5 / –19.39	69.4 ± 0.9 / 5.04	4.5 ± 0.3 / –14.91	5.82
VK69xAE746	9.4 ± 0.4 / –28.19	68.7 ± 0.4 / –0.06	4.6 ± 0.2 / –23.62	5.41
VK69xFV243	8.3 ± 0.2 / –26.95	73.1 ± 0.2 / 2.61	4.5 ± 0.1 / –7.00	5.77
VK69xAK159	7.8 ± 0.2 / –27.12	70.4 ± 0.8 / 0.52	3.4 ± 0.1 / –30.19	5.47
Conditional standard	8.9	69.4	4.3	6.01
$LSD_{0.05}$	0.68	4.85	0.34	0.41

Within this group of hybrids, there are three combinations: AE801xFV243 (11.18%), - with high protein content; very high content of starch grain was observed in hybrid AE801xVK32 (70.83%), hybrid AE801xAE746 was characterized by significantly higher than the standard protein and oil content (11.27% and 5.13%, respectively).

In 2020, MPH was detected in the hybrid AE801xVK32 by starch content. In 2021, positive MPH was detected in hybrids AE801xVK19, AE801xVK32, and AE801xCO255 (Table 4).

Table 4. Description of hybrids with maternal form AE801 (2020–2021)

Hybrid formula	Content in the grain, % / MPH, %			Yield, t ha^{-1}
	Protein	Starch	Oil	
	2020			
AE801xAE746	11.0 ± 0.4 / –19.79	66.7 ± 0.4 / –1.60	5.1 ± 0.1 / –11.03	2.82
AE801xVK32	8.8 ± 0.2 / –32.75	70.6 ± 0.9 / 2.19	3.8 ± 0.2 / –20.69	5.14
AE801xCO255	10.1 ± 0.3 / –24.84	68.5 ± 0.2 / –1.35	4.5 ± 0.2 / –9.82	3.82
AE801xAK159	9.9 ± 0.3 / –14.52	68.2 ± 0.3 / 1.12	4.2 ± 0.1 / –19.64	5.53
AE801xVK19	9.0 ± 0.3 / –30.55	65.4 ± 0.3 / –0.56	3.8 ± 0.1 / –31.54	5.02
AE801xFV243	11.5 ± 0.3 / –9.55	67.1 ± 0.4 / –1.73	4.7 ± 0.1 / –8.02	6.27
AE801xVK13	9.6 ± 0.2 / –26.14	68.2 ± 0.5 / –1.01	4.2 ± 0.1 / –16.84	5.14
AE801xAE800	9.4 ± 0.2 / –22.64	65.1 ± 0.5 / –3.33	4.8 ± 0.1 / –12.47	3.27
Conditional standard	9.8	67.5	4.2	5.45
$LSD_{0.05}$	0.53	5.27	0.24	0.48
	2021			
AE801xAE746	11.5 ± 0.4 / –13.83	64.2 ± 0.4 / –2.41	5.1 ± 0.1 / –8.83	3.18
AE801xVK32	9.3 ± 0.4 / –27.74	71.0 ± 0.6 / 4.03	3.8 ± 0.1 / –19.58	4.42
AE801xCO255	10.2 ± 0.4 / –22.76	68.3 ± 0.5 / 5.25	4.2 ± 0.1 / –15.14	4.65
AE801xAK159	9.6 ± 0.3 / –21.79	67.8 ± 0.5 / –1.56	3.9 ± 0.1 / –21.22	5.75
AE801xVK19	8.7 ± 0.2 / –30.91	69.8 ± 0.5 / 7.44	3.9 ± 0.1 / –27.08	4.20
AE801xFV243	10.9 ± 0.2 / –14.42	69.6 ± 0.4 / 0.90	4.2 ± 0.2 / –15.84	6.09
AE801xVK13	10.4 ± 0.3 / –19.66	66.7 ± 0.5 / –3.40	4.6 ± 0.2 / –6.58	8.72
AE801xAE800	8.5 ± 0.2 / –30.72	65.3 ± 0.3 / –7.09	4.4 ± 0.2 / –19.65	4.18
Conditional standard	9.6	67.6	4.2	6.02
$LSD_{0.05}$	0.69	4.71	0.33	0.46

The inbred maize line AE392, which has a high oil content (Zhemoida et al., 2020) acted as the maternal form of a group of experimental hybrids, including the hybrid AE392xHLG1203 with a significantly higher oil content compared to competitors in its group - 5.83%). According to the obtained data from laboratory analyses, it should be noted that the protein content in this group of hybrids was 9.9–10.8% (s = 0.5757), starch 67.10–68.27% (s = 0.575), oil 4.37–5.83% (s = 0.2204) - average values for years of research.

In this group of hybrids, MPH was manifested only in terms of oil content in grain: 2020 - in hybrids AE392xCO255, AE392xHLG1203, AE392xAK157; in 2021 - hybrids AE392xVK19, AE392xCO255, and AE392xHLG1203 (Table 5).

Table 5. Description of hybrids with maternal form AE392 (2020–2021)

Hybrid formula	Content in the grain, % / MPH, %			Yield,
	Protein	Starch	Oil	t ha^{-1}
	2020			
AE392xHLG1203	10.4 ± 0.2 / –11.08	67.4 ± 0.5 / –0.36	5.6 ± 0.2 / 35.00	3.45
AE392xCO255	10.4 ± 0.3 / –16.67	68.3 ± 0.5 / –1.24	4.8 ± 0.2 / 14.08	4.65
AE392xAK157	9.7 ± 0.4 / –16.23	67.7 ± 0.5 / –4.13	5.1 ± 0.1 / 17.48	6.55
AE392xAE800	10.4 ± 0.4 / –7.33	68.8 ± 0.3 / –1.97	4.3 ± 0.2 / –7.83	3.75
AE392xQ170	10.5 ± 0.3 / –13.11	68.4 ± 0.3 / –0.69	4.6 ± 0.1 / 9.36	2.75
AE392xVK19	10.5 ± 0.3 / –12.81	66.1 ± 0.7 / –3.67	5.1 ± 0.2 / 5.80	3.31
AE392xAE746	10.8 ± 0.4 / –15.74	67.2 ± 0.2 / –4.09	4.0 ± 0.1 / –19.90	2.96
AE392xUHK686	7.9 ± 0.4 / –34.07	66.0 ± 0.7 / –7.03	4.2 ± 0.1 / 2.72	3.91
Conditional standard	10.1	68.0	4.7	3.92
$LSD_{0.05}$	0.69	6.53	0.50	0.31
	2021			
AE392xHLG1203	10.7 ± 0.3 / –10.96	66.6 ± 0.5 / –9.95	6.1 ± 0.2 / 42.71	2.73
AE392xCO255	11.2 ± 0.3 / –11.10	67.7 ± 0.8 / –2.86	5.1 ± 0.1 / 18.60	3.70
AE392xAK157	10.1 ± 0.2 / –12.93	68.8 ± 0.5 / –2.96	4.9 ± 0.1 / 11.91	5.90
AE392xAE800	10.7 ± 0.4 / –8.48	66.3 ± 0.9 / –8.06	4.4 ± 0.1 / –7.54	3.72
AE392xQ170	9.7 ± 0.3 / –19.74	68.0 ± 0.6 / –8.13	4.2 ± 0.1 / –2.75	3.55
AE392xVK19	10.5 ± 0.4 / –12.21	68.1 ± 0.3 / 1.81	6.4 ± 0.3 / 34.24	2.99
AE392xAE746	9.9 ± 0.2 / –21.83	68.3 ± 0.3 / 0.05	4.4 ± 0.1 / –12.56	3.88
AE392xUHK686	8.1 ± 0.2 / –33.91	68.8 ± 0.4 / –3.28	4.2 ± 0.1 / 4.68	3.17
Conditional standard	10.1	67.3	5.0	3.71
$LSD_{0.05}$	0.75	6.17	0.43	0.33

Endosperm mutants favorably change the consistency of maize grain, but they also cause certain undesirable consequences, as is expected of most mutants. Since the kernel weight is reduced due to less density per unit volume as starch is loosely packed with a lot of air spaces, there is a corresponding decline in the yield (Toro et al., 2003; Singh & Venkatesh, 2006).

Simultaneously with the study of the main biochemical parameters, the yield of experimental hybrids was also determined. A comparison of hybrids by yield level in 2020–2021 was conducted separately for each group formed by maternal forms.

The average yield of the group of hybrids with the maternal form VK13 was 5.99 t h^{-1}. The highest yield in this group was formed in the hybrid VK13xUHK686 - 7.63 t h^{-1}, in general, the yield varied between 2.93–7.63 t h^{-1}.

The highest average yield of 6.46 t h^{-1} was shown by the group whose maternal form of hybrids was the inbred line VK69. Within this group, the yield of hybrids varied between 4.20 and 9.37 t h^{-1}. The highest yield was recorded in the hybrid VK69xG255 - 9.37 t h^{-1}.

In the group of hybrids with the parent component AE801, the average yield was 5.74 t h^{-1} and was in the range of 3.0–8.63 t h^{-1}. The best yield in this group was the hybrid AE801xVK13 - 8.63 t h^{-1}.

The yield of the hybrids group with the parent component AE392 varied between 3.09–6.23 t h^{-1}, and the average value was 3.92 t h^{-1}. The highest yield in this group was formed by the hybrid AE392xAK157 - 6.23 t h^{-1}.

CONCLUSIONS

The use of inbred lines VK13, and VK69 - as sources of mutations in the gene structure of the endosperm structure *waxy* and AE801 and AE392 - mutations *ae* affects the creation of hybrids with improved grain quality and high yields.

As a result of the analysis of experimental data on the content of new hybrids of the main biochemical components in maize grain, the following are distinguished within their groups:

– high in protein: VK13xCO255 - 13.07%, VK13xVK37 - 12.60%, AE801xAE746 - 11.27%, AE801xFV243 - 11.18%;

– with a high starch content: VK13xUHK678 - 72.60%, VK13xUHK686 - 72.57%, VK69xFV243 - 72.80%, AE801xVK32 - 70.83%.

– with high oil content: VK13xUHKK686 - 5.07%, VK13xVK37 - 5.27%, VK69xVK13 - 5.27%, AE801xAE746 - 5.13%, AE392xHLG1203 - 5.83%.

According to the level of yield, hybrids were identified: VK69xG255 with a yield of 9.37 t h^{-1} and AE801xVK13 with a yield of 8.63 t h^{-1}.

According to the set of valuable economic indicators hybrids VK13xCO255 - high protein content and yield; VK13xVK37 and AE801xAE746 - simultaneously high content of protein and oil; VK13xUHK686 - high content of starch, oil, and yield.

Inbred maize lines CO255, UHK686, VK37, FV243, AE746, and others are a valuable breeding material (parent component) for the creation of new hybrids with a set of improved grain quality indicators.

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