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ОЦЕНКА КОМБИНАЦИОННОЙ СПОСОБНОСТИ ЛИНИЙ КУКУРУЗЫ НА СОДЕРЖАНИЕ КРАХМАЛА

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Представлены результаты исследования содержания крахмала в гибридных комбинациях кукурузы. В результате изучения экспериментальных гибридов, созданных на основе коллекционного материала ВИР, выявлена селекционная и комбинационная ценность линий по содержанию в зерне и выходу крахмала с 1 га. Приведены результаты по сбору крахмала с единицы площади. В эксперимент включены простые гибриды (30 комбинаций), полученные по полной топкроссной схеме скрещиваний. В исследовании в качестве тестеров использованы линии РСК 7, Б 293 и синтетическая популяция РНИИСК 1. Интервал варьирования содержания крахмала в зерне за изучаемый период изменялся от низких значений до среднего показателя. В 2020 г. он составил от 60,9 до 65,2%, в 2021 г. – от 59,3 до 66,1%. Выделены линии с высоким эффектом общей комбинационной способности по содержанию крахмала в зерне (Х 46, Вз 6, Ом 12, ЮВ 106), а также гибридные комбинации ЮВ 25 / РСК 7 (63,3–64,2%), КС 75 / РСК 7 (62,7–64,4), ХЛГ 948 / РСК 7 (63,5–64,1), Кин 073 / РСК 7 (63,4–63,8), ЮВ 106 / РСК 7 (63,6–66,1), КС 25 / Б 293 (63,0–63,5), ХЛГ 182 / Б 293 (63,5–63,6), КС 75 / Б 293 (63,1–63,5), ХЛГ 182 / РНИИСК 1 (62,9–63,6%). Выявлены экспериментальные гибриды, формирующие наибольший выход крахмала с единицы площади: ХЛГ 182 / РСК 7 (3,12–3,58 т/га), ЮВ 106 / РСК 7 (2,77–3,11), Х 46 / Б 293 (3,22–3,39), Ом 12 / Б 293 (2,72–3,85 т/га).

Ключевые слова: гибрид, общая комбинационная способность, специфическая комбинационная способность, тестер, скрещивание, дисперсия

EVALUATION OF COMBINATION ABILITY OF CORN LINES FOR STARCH CONTENT

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The results of the study of starch content in corn hybrid combinations are presented. As a result of the study of experimental hybrids created on the basis of VIR collection material, the breeding and combinational value of the lines in terms of grain content and starch yield per 1 ha was revealed. The results of starch harvesting per unit area are given. The experiment includes simple hybrids (30 combinations) obtained using the full topcross crossing scheme. In the study, the RCK 7, B 293 lines and the synthetic population of RNIISK 1 were used as testers. The interval of variation of starch content in the grain during the study period varied from low values to the average indicator. It was 60.9% to 65.2% in 2020, and 59.3% to 66.1% in 2021. The lines with high effect of total combining ability by starch content in the grain (X 46, Bz 6, Om 12, YuV 106), and hybrid combinations of YuV 25 / RSK 7 (63, 3-64.2%), KS 75 / RSK 7 (62.7-64.4), KhLG 948 / RSK 7 (63.5-64.1), Kin 073 / RSK 7 (63.4-63.8), YuV 106 / RSK 7 (63.6-66, 1), KS 25 / B 293 (63.0-63.5), KhLG 182 / B 293 (63.5-63.6), KS 75 / B 293 (63.1-63.5), KhLG 182 / RNIISK 1 (62.9-63.6%) were identified. The experimental hybrids that form the highest yield of starch per unit area were identified: KhLG 182 / RSK 7 (3,12-3,58 t/ha), YuV 106 / RSK 7 (2,77-3,11), X 46 / B 293 (3,22-3,39), Om 12 / B 293 (2,72-3,85 t/ha).

Keywords: hybrid, general combining ability, specific combining ability, tester, crossing, dispersion

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Conflict of interest
The authors declare no conflict of interest.

INTRODUCTION

Self-pollinated lines are the basis for the breeding process [1]. The breeding value of the lines used determines the quantitative and qualitative traits of the hybrids created, which must meet the specific requirements of modern agricultural production [2]. The production of starch from corn grain holds significant economic and food value [3]. Therefore, it is necessary to identify lines capable of producing hybrids with high starch content in the grain and high yield per unit area [4, 5].

The evaluation of the combining ability at a later stage of selection is usually conducted based on testing hybrids using a complete diallel cross scheme [6, 7]. However, this scheme requires obtaining a large number of hybrids and becomes challenging when dealing with a large number of the lines under study [8]. When selecting the best samples from a large population, the topcross method is more appropriate [9]. In this case, instead of crossing lines with each other, two to three common parents with broad genetic backgrounds (lines, varieties, synthetic populations) are used [10, 11]. This is necessary to fully capture the genetic variability present among the lines and identify the best combinations for specific traits [12]. Crossing lines with testers allows for obtaining information about both their general combining ability (GCA) and specific combining ability (SCA) without resorting to diallel crosses, provided that several good inbred lines are used as testers [13]. If the magnitude of heterosis in the hybrid combination of a line with a tester is significantly higher than expected based on the line's general combining ability, it is possible to infer high specific combining ability. High SCA effects can be achieved when crossing lines not only with high GCA but also with low GCA [14, 15].

The purpose of this study is to evaluate the general and specific combining ability of inbred corn lines based on test crosses using a complete topcross scheme and identify the best parental lines for use in selection to improve starch yield.

MATERIAL AND METHODS

The research was conducted in 2020 and 2021 at the experimental field of the Russian Research Institute for Sorghum and Maize (RosNIISK "Rossorgo") according to the methodology[1]. The climate of the region is characterized as sharply continental. The average annual temperature during the study years ranged from 0.56 to 1.05. The soil of the experimental site is a moderately heavy, low-humus, southern chernozem. The experiment included simple hybrids (30 combinations) obtained through a complete topcross breeding scheme. The testers used were the RSK 7 lines, B 293, and the synthetic population RNIIISK 1, which have a wide genetic basis. The selection of testers was based on their different origins and corresponding genotypic diversity, which allowed for a more comprehensive evaluation of the expression of combinatorial ability parameters. The experiment was replicated three times. The size of the plot was 7.7 m^2, with a length of 5.5 m. The plant density was 50,000 plants/ha. The agricultural techniques used in the experiment were zonal and developed at RosNIISK "Rossorgo". The corresponding methodolo-

[1]*Dospekhov B.A.* Methodology of field experience. Moscow: Agropromizdat, 1985. 351 p.

gies[2, 3] were employed for data collection, observations, and determination of combinatorial ability. Data analysis was performed using the Agros-2.09 computer program.

RESULTS AND DISCUSSION

Starch is the main biochemical indicator that characterizes the quality of grain intended for the production of food starch. The expansion of food usage of maize grain is driven by the need to create and study the initial material for breeding hybrids with high starch content suitable for application in the starch industry [16]. Additionally, the majority of energy obtained by livestock through feeding comes from carbohydrates.

The obtained data indicate significant differences between hybrids in terms of starch content in the grain (see Table 1). The range of starch content variation in the grain over the study period ranged from low to moderate values, with values ranging from 60.9% to 65.2% in 2020 and from 59.3% to 66.1% in 2021. The skewness coefficient indicates a nearly symmetric distribution of the trait in 2020 and a right-skewed distribution in 2021. However, the coefficients of variation indicate insignificant differences among hybrids in terms of starch content in the grain.

The evaluation of the biochemical composition of the grain allowed for the identification of starch content in the grain (see Table 2). It is considered justified to cultivate maize for feed purposes when the starch content in whole plants is no less than 35-40% [17]. The amount of starch in the grain varied depending on the composition of the combinations and averaged for hybrids including the testers: RSK 7 - 62.3-62.8%, B 293 - 62.5-63.2%, RNIIISK 1 - 61.8-63.3%. The highest starch content was observed in the following combinations: YuV 25 / RSK 7 (63.3-64.2%), KS 75 / RSK 7 (62.7-64.4%), KhLG 948 / RSK 7 (63.5-64.1%), Kin 073 / RSK 7 (63.4-63.8%), YuV 106 / RSK 7 (63.6-66.1%), KS 25 / B 293 (63.0-63.5%), KhLG 182 / B 293 (63.5-63.6%), KS 75 / B 293 (63.1-63.5%), KhLG 182 / RNIIISK 1 (62.9-63.6%).

Табл. 1. Параметры статистической оценки гибридов по содержанию крахмала в зерне

Table 1. Parameters of statistical evaluation of hybrids by starch content in grain

Parameter	2020	2021
Mean value, %	63,1	62,2
Min, %	60,9	59,3
Max, %	65,2	66,1
LSD_{05}	2,57	2,41
Error of the mean value	0,14	0,20
Dispersion	0,85	1,58
Standard deviation	0,92	1,37
Coefficient of variation	1,46	2,20
Skew coefficient	0,084 ns	0,397 ns
Skew coefficient error	0,354	0,354
Coefficient of excess	–0,167 ns	0,419 ns
Coefficient of excess error	0,693	0,693

The range of starch yield per unit area over the study period varied from 1.74 to 3.85 t/ha. The skewness coefficients indicate a right-skewed distribution of the trait in the sample in 2020 and 2021 (0.311-0.709), while the coefficients of variation suggest a moderate degree of variation among hybrids in terms of starch yield per 1 ha (13.8%).

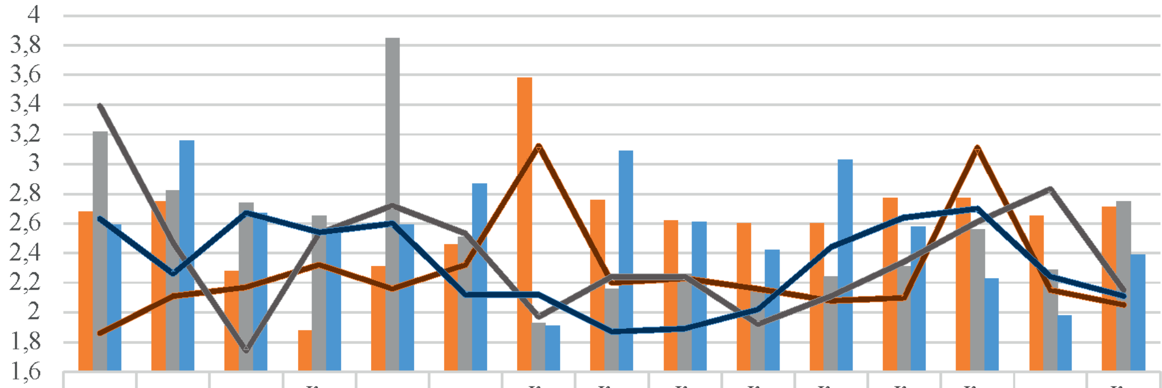
The evaluation of grain yield and biochemical composition allowed for the identification of starch yield per 1 ha (see Figure 1). Starch collection from the grain varied depending on the composition of combinations and averaged for hybrids including the tester: RSK 7 - 2.28-2.63 t/ha, B 293 - 2.39-2.56 t/ha, RNIIISK 1 - 2.32-2.58 t/ha. The highest starch yield was obtained in the following combinations: KhLG 182 / RSK 7 (3.12-3.58 t/ha), YuV 106 / RSK 7 (2.77-3.11 t/ha), X 46 / B 293 (3.22-3.39 t/ ha), Om 12 / B 293 (2.72-3.85 t/ha). The range of variation in GCA effects for starch content in

[2]Methods of state variety testing of agricultural crops. Crops, cereals, legumes, corn and fodder crops // Gosagroprom of the USSR. State Commission for variety testing of agricultural crops. Moscow, 1989.Vol. 2. 194 p.

[3] Fedin M.A., Silis D.Y., Smiryaev A.V. Statistical methods of genetic analysis. Moscow: Kolos, 1980. 208 p.

Табл. 2. Содержание крахмала в зерне гибридов кукурузы, %
Table 2. Starch content in corn hybrids grain, %

Line	Tester					
	RSK7		B293		RNIISK 1	
	2020	2021	2020	2021	2020	2021
к-16285 X 46	62,0	62,6	63,0	62,6	62,0	61,8
к-17239 Vz 6	62,0	61,6	62,5	62,5	64,3	62,2
к-19071 YuV 24	62,0	61,8	62,0	61,7	64,8	60,2
к-19072 YuV 25	63,3	64,2	62,9	61,9	64,3	62,6
к-19464 Om 12	63,2	61,1	64,4	62,1	62,1	62,4
к-20095 KS 25	62,7	64,4	63,5	63,0	63,8	61,3
к-20735 KhLG 182	63,1	60,6	63,5	63,6	62,9	63,6
к-21188 KhLG 898	63,4	61,6	64,0	63,1	62,7	62,3
к-21214 KhLG 948	63,5	64,1	65,2	62,3	62,6	60,2
к-21286 KhLG 1325	60,9	60,6	63,0	60,7	64,4	63,2
к-21301 KhLG 1372	63,2	61,1	63,1	63,3	64,4	60,0
к-21522 Kin 073	63,8	63,4	62,2	64,5	63,0	62,2
к-22050 YuV 106	63,6	66,1	63,3	60,4	61,5	61,5
к-22087 KS 75	62,8	59,3	63,1	63,5	62,3	61,7
к-22090 KS 101	62,3	61,7	62,8	61,9	64,4	61,3
Mean value	62,8	62,3	63,2	62,5	63,3	61,8



к-16285 Х 46	к-17239 Вз 6	к-19071 ЮВ 24	к-19072 ЮВ 25	к-19464 Ом 12	к-20095 КС 25	к-20735 ХЛГ 182	к-21188 ХЛГ 898	к-21214 ХЛГ 948	к-21286 ХЛГ 1325	к-21301 ХЛГ 1372	к-21522 Кин 073	к-22050 ЮВ 106	к-22087 КС 75	к-22090 КС 101
2,68	2,75	2,28	1,88	2,31	2,46	3,58	2,76	2,62	2,6	2,6	2,77	2,77	2,65	2,71
3,22	2,82	2,74	2,65	3,85	2,51	1,93	2,16	2,26	2,15	2,24	2,31	2,56	2,29	2,75
2,59	3,16	2,67	2,53	2,59	2,87	1,91	3,09	2,61	2,42	3,03	2,58	2,23	1,98	2,39
1,86	2,11	2,17	2,32	2,16	2,32	3,12	2,2	2,23	2,16	2,08	2,1	3,11	2,15	2,05
3,39	2,47	1,74	2,53	2,72	2,53	1,97	2,24	2,24	1,92	2,11	2,34	2,61	2,83	2,15
2,63	2,26	2,67	2,54	2,6	2,12	2,12	1,87	1,89	2,02	2,44	2,64	2,7	2,24	2,11

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Рис. 1. Выход крахмала зерна у гибридов кукурузы с 1 га (2020, 2021 гг.), т/га
Fig. 1. Grain starch yield of corn hybrids from 1 ha (2020, 2021), t/ha

the grain ranged from -0.89 to 0.54 in 2020 and from -1.25 to 0.88 in 2021 (see Table 3). High GCA values were observed for lines in 2020 - YuV 25, KhLG 948, KhLG 1372, and in 2021 - YuV 25, KS 25, Kin 073.

The variance of SCA for starch content in the grain in 2020 ranged from 0.09 to 3.06, and in 2021, it ranged from 0.14 to 9.81. The highest positive SCA variance in 2020 was observed for the variety samples k-17239 Vz 6, k-19071 YuV 24, k-19464 Om 12, k-21214 KhLG 948, k-21286 KhLG 1325, and in 2021 - k-20095 KS 25, k-20735 KhLG 182, k-21214 KhLG 948, k-21301 KhLG 1372, k-22050 YuV 106, k-22087 KS 75. The ratio of mean squares of GCA to SCA deviations in 2020 was 2.38, and in 2021, it was 1.16. It can be concluded that there is a predominance of additive gene interaction in the formation and content of starch.

The range of variation in GCA effects for starch yield per hectare in 2020 ranged from -0.34 to 0.26, and in 2021, it ranged from -0.33 to 0.44 (see Figure 2). High GCA effects were observed in 2020 for the lines X 46, Vz 6, Om 12, and in 2021 for Kh 46, YuV 106. The variance of SCA for the lines ranged from 0.03 to 0.82 in 2020, and from 0.01 to 0.53 in 2021. The highest positive SCA variance in 2020 was observed for the variety samples k-19464 Om 12, k-20735 KhLG 182, and in 2021 for k-16285 X 46, k-20735 KhLG 182, k-19071 YuV 24. The ratio of mean squares of GCA to SCA deviations in 2020 was 1.16, and in 2021 it was 2.90, indicating the influence of additive gene effects on the amount of harvested starch.

The effects of general and specific combining ability are associated with the genetic diversity of the specific breeding material reflected in the gene effects. Gene effects can vary depending on the growth conditions. Thus, the parameters of GCA and SCA are also subject to ecological variability[4]. This parameter characterizes individual combinations and is measured by the deviation of the trait in a specific cross based on the average quality of the studied parental forms. In 2020 and 2021, the following hybrids were characterized by high SCA effects for starch content in the grain: Kin 073 / RSK 7, YuV 106 / RSK 7, X 46 / B 293, Om 12 / B 293, KhLG 182 / B 293, KhLG 898 / B 293, KS 75 / B 293, KhLG 1325 / RNIIISK 1 (see Table 4).

Табл. 3. Эффекты ОКС и дисперсия СКС линий по признаку «содержание крахмала в зерне», %

Table 3. Effects of GCA and variance of SCA lines according to the "starch content in grain", %

Line	GCA effect		SCA dispersion	
	2020	2021	2020	2021
к-16285 X 46	–0,89	–0,15	0,33	0,32
к-17239 Вз 6	–0,29	–0,38	1,44	0,14
к-19071 YuV 24	–0,29	–1,25	2,59	1,00
к-19072 YuV 25	0,27	0,42	0,52	1,64
к-19464 Om 12	0,01	–0,62	1,32	0,31
к-20095 KS 25	0,10	0,42	0,31	2,80
к-20735 KhLG 182	–0,06	0,12	0,09	2,61
к-21188 KhLG 898	0,14	–0,15	0,42	0,46
к-21214 KhLG 948	0,54	–0,28	1,74	4,30
к-21286 KhLG 1325	–0,46	–0,98	3,06	1,90
к-21301 KhLG 1372	0,34	–1,02	0,51	2,90
к-21522 Kin 073	–0,23	0,88	0,66	1,44
к-22050 YuV 106	–0,43	0,18	1,31	9,81
к-22087 KS 75	–0,49	–0,98	0,16	4,08
к-22090 KS 101	–0,06	–0,85	1,18	0,15

The hybrids characterized by high SCA effects for starch yield per 1 ha in 2020 and 2021 were: KhLG 182 / RSK 7, YuV 106 / RSK 7, X 46 / B 293, Om 12 / B 293, KhLG 1372 / RNIIISK 1, YuV 24 / RNIIISK 1 (see Figure 3).

CONCLUSION

The study of experimental hybrids created based on the VIR germplasm revealed their breeding and combining value in terms of starch content in the grain and starch yield per hectare. Lines with high GCA effects for starch content in the grain were identified (X 46, Vz 6, Om 12, YuV 106), as well as hybrid combinations YuV 25 / RSK 7 (63.3-64.2%), KS 75 / RSK 7

[4] Smiryaev A.V., Kilchevsky A.V. Genetics of populations and quantitative traits. Moscow: KolosS, 2007. 272 p.

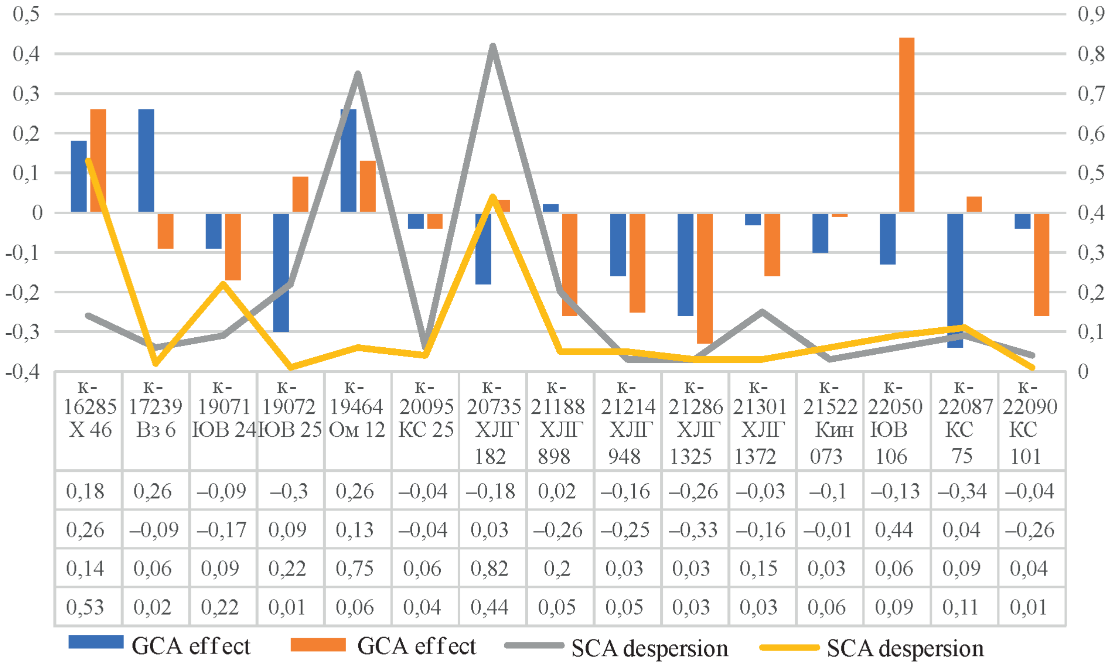

Рис. 2. Эффекты ОКС и дисперсии СКС линий по признаку «выход крахмала с 1 га», т/га

Fig. 2. Effects of GCA and variance of SCA lines according to the "starch yield per 1 ha", t/ha

Табл. 4. Эффекты СКС гибридов по признаку «содержание крахмала в зерне», %

Table 4. Effects of SCA of hybrids according to the "starch content in grain", %

Line	Tester					
	RSK7		B 293		RNIISK 1	
	2020	2021	2020	2021	2020	2021
к-16285 X 46	–0,32	0,40	0,66	0,24	–0,34	–0,64
к-17239 Vz 6	–0,92	–0,36	–0,44	0,37	1,36	–0,01
к-19071 YuV 24	–0,92	0,70	–0,94	0,44	1,86	–1,14
к-19072 YuV 25	–0,18	1,44	–0,61	–1,03	0,79	–0,41
к-19464 Om 12	–0,02	–0,63	1,16	0,21	–1,14	0,42
к-20095 KS 25	–0,62	1,64	0,16	0,07	0,46	–1,71
к-20735 KhLG 182	–0,05	–1,86	0,33	0,97	–0,27	0,89
к-21188 KhLG 898	0,05	–0,60	0,63	0,74	–0,67	–0,14
к-21214 KhLG 948	–0,25	2,03	1,43	0,07	–1,17	–2,11
к-21286 KhLG 1325	–1,85	–0,77	0,23	–0,83	1,63	1,59
к-21301 KhLG 1372	–0,35	–0,23	–0,47	1,81	0,83	–1,58
к-21522 Kin 073	0,82	0,17	–0,81	1,11	–0,01	–1,28
к-22050 YuV 106	0,82	3,57	0,49	–2,29	–1,31	–1,28
к-22087 KS 75	0,08	–2,07	0,36	1,97	–0,44	0,09
к-22090 KS 101	–0,85	0,20	–0,37	0,24	1,23	–0,44

(62.7-64.4%), KhLG 948 / RSK 7 (63.5-64.1), Kin 073 / RSK 7 (63.4-63.8), YuV 106 / RSK 7 (63.6-66.1), KS 25 / B 293 (63.0-63.5), KhLG 182 / B 293 (63.5-63.6), KS 75 / B 293 (63.1-63.5), KhLG 182 / RNIISK 1 (62.9-63.6%). The results of the study allowed for the identification of experimental hybrids that showed the highest starch yield per unit area: KhLG 182 / RSK 7 (3.12-3.58 t/ha), YuV 106 / RSK 7 (2.77-3.11), X 46 / B 293 (3.22-3.39), Om 12 / B 293 (2.72-3.85 t/ha).

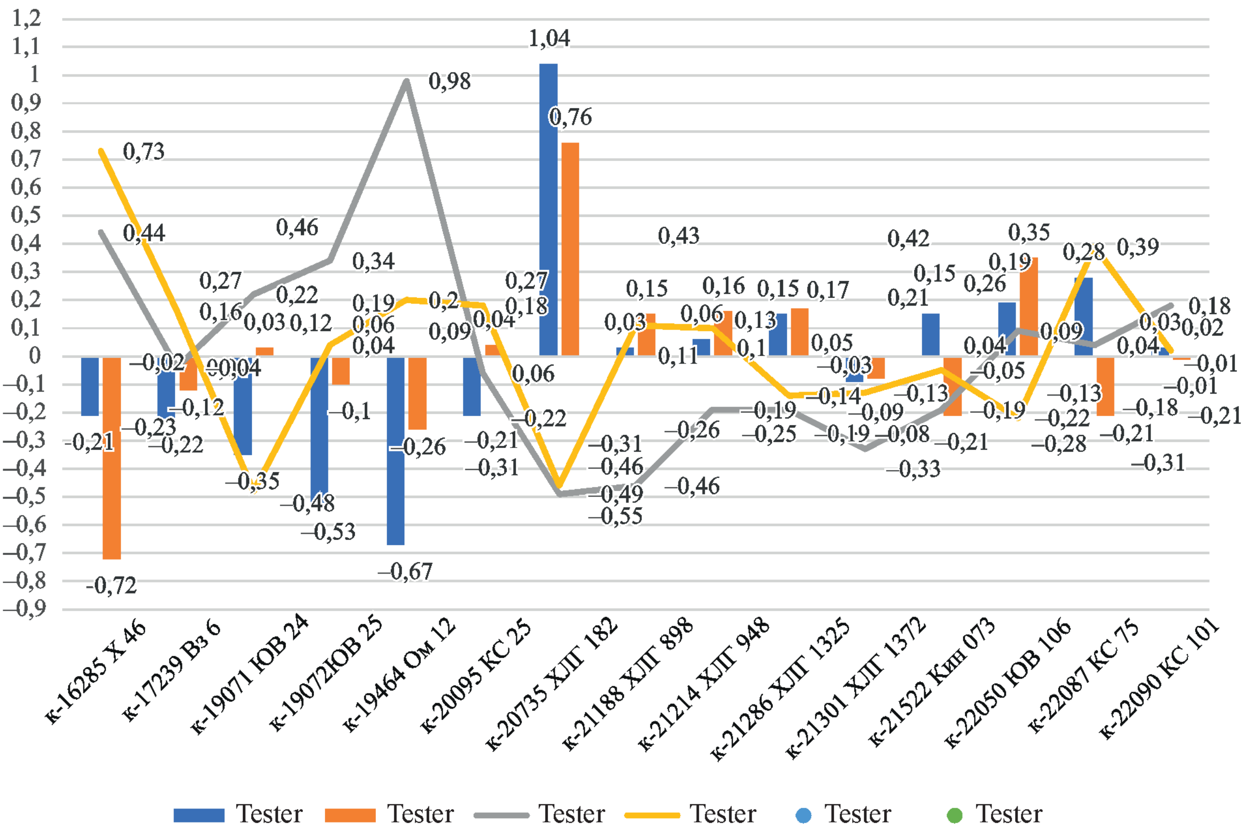

Рис. 3. Эффекты СКС гибридов по признаку «выход крахмала с 1 га» (2020, 2021 гг.), т/га

Fig. 3. Effects of SCA hybrids according to the "starch yield per 1 ha" (2020, 2021), t/ha

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