

**BREEDING SUGAR-FODDER BEET HYBRIDS FOR BIOFUEL PRODUCTION****M. O. Kornieieva***Institute of Bioenergy Crops and Sugar Beet of the NAAS of Ukraine, 25 Klinichna St., Kyiv, 03141, Ukraine*

**Topicality.** The development of biofuel engineering in Ukraine demands to cultivate the agrofuel crops as renewable energy sources. The sugar-fodder hybrids created using high-value sterile forms of sugar beet and fertile forms of fodder beet may hold promise for biofuel feedstock production. **Purpose.** Developing experimental sugar-fodder beet hybrids with high energy yield that are suitable for alternative biofuels production, and selecting the best ones. **Materials and Methods.** To create the sugar-fodder hybrids, 6 pollen-sterile sugar lines and 23 breeding numbers of fertile fodder beet were used. The stages of the breeding process included the selection of the original parental lines, their evaluation for combining ability, and the formation of hybrids based on the best of them. The method of multi-tester top crosses and field trials of experimental hybrids were used. **Results.** The parent components significantly varied in energy yield, which ranged within 53.5–61.5 GJ/ha for the MS-samples, and from 80.0 to 87.8 GJ/ha for the 4 best pollinators. According to the results of test crosses, we selected the MS forms of sugar beet lines Iv. 24869 and MS Iv. 2484 of Ivanivka origin with significantly high effects of total combining ability of 6.7 and 4.0 GJ/ha and fodder beet pollinators-varieties Halyskyi and Lvivskyi Zhovtyi – 8.0 and 6.5 GJ/ha, respectively. In the genotypic structure of sugar yield trait variability, the total share of the influence of valuable additive complexes of parental genes (51 %) was almost equal to the share of non-additive interaction of components (49 %). **Conclusions.** Three new genotypes of sugar-fodder hybrids suitable for the biofuel production from renewable sources with energy yield above 120 GJ/ha were created by combination breeding. These genotypes are MS Iv. 24869/k 41/42; MS Iv. 24869/k 13/14 and MS Iv. 24869/Lvivskyi Zhovtyi variety, which exceed the standard by 14.3, 15.4 and 8.5 %, respectively.

**Key words:** bioenergy, pollen-sterile forms, pollinators, sugar-fodder hybrids, combining ability, energy yield

**Introduction.** The rapid development of bioenergy, which is a global trend, helps to reduce fuel imports, replacing a significant share of traditional energy resources and thereby enhancing Ukraine's security [1]. Therefore, agricultural science is orientating Ukraine's agricultural sector towards growing energy crops as renewable energy sources.

In view of the economical use of traditional energy sources, environmental preservation, and the development of a promising area of Ukraine's agricultural sector, crops such as miscanthus, switchgrass, osier willow, sorghum, poplar, etc. are currently being studied and grown. [2]. Another bioenergy crop suitable for the alternative fuels production is beet (*Beta vulgaris* L.), both sugar and fodder beet. In addition, sugar-fodder beet hybrids created based on valuable pollen-sterile forms of sugar beet and valuable fertile forms of fodder beet may have breeding prospects [2, 3]. The efficiency of breeding work of these hybrids depends on the

involvement of donors and sources of valuable traits – carriers of gene complexes that control the significant breeding traits of sugar beet bioenergy potential [4, 5].

Domestic research institutions, such as the Institute of Bioenergy Crops and Sugar Beet (IBCSB) and its network, the Institute of Agriculture (NSC IA), the Institute of Agriculture in the Carpathian Region (IACR) and others have trait collections of pollen-sterile forms of sugar beet, as well as fertile forms of fodder beet (lines, cultivars, varieties, breeding numbers) that can be used to develop sugar-fodder hybrids based on cytoplasmic male sterility that are suitable for the production of alternative biofuels [6]. The genetic potential of productivity can be more fully revealed by hybridisation of newly developed lines, previously evaluated for combining ability. These studies are based on the results of earlier experiments to create new beet genotypes with increased bioenergy potential (bioethanol yield, energy yield) [3, 6].

**Author information:**

**Myroslava O. Kornieieva**, Candidate of Biological Sciences, Senior Researcher, Leading Researcher of the Sugar Beet Breeding Laboratory, e-mail: mira31@ukr.net, <http://orcid.org/0000-0001-7266-0970>

The *purpose* of the research was to create experimental sugar-fodder beet hybrids with high energy yield and suitable for alternative biofuels, and to select the best of them.

**Materials and Methods.** In 2015–2020, the research was carried out at the Institute of Bioenergy Crops and Sugar Beet of NAAS of Ukraine (IBCSB). The initial materials for the breeding sugar-fodder hybrids were 6 diploid sterile lines (maternal form) of Ivanivka, Yaltushkiv, Uman and Uladivka origin from the IBCSB network, as well as 23 diploid fodder beet cultivars (varieties, inbred lines, products of individual selection, hybrid samples on a fertile basis) originated by the Institute of Agriculture in the Carpathian Region (IACR), which were used as pollinators (parental form) to pollen-sterile (MS) forms.

The technological stages of the breeding process for developing sugar-fodder beet hybrids based on cytoplasmic male sterility (CMS) for the production of alternative biofuels were as follows: selection of initial forms MS lines of sugar beet and pollinators of fodder beet, their breeding improvement due to selections based on their economically valuable traits; top crosses to determine the combining ability of components; formation of hybrid combinations according to the scheme of one-way cyclic crosses and

variety testing of hybrid samples. Evaluation and selection of the best hybrid combinations with a high productivity and energy yield was based on genetic and statistical analysis of breeding numbers compared to the group standard, which included three best domestic varieties. The predecessor was winter cereals. Wide-row sowing method was used with row spacing of 45 cm. The plot area was 13.5 m<sup>2</sup>. The replication rate was three times..

The analysis of the breeding value of the initial genotypes in terms of root crop yield, sugar content, and dry matter content was carried out according to the method [7]. Energy indicators were determined by the following method [8].

**Results.** The pollen-sterile forms involved in the experiment as initial materials were of different ecological and genetic origin. Three lines were bred at the Ivanivka Experimental Breeding Station, one line was originated from the Yaltushkivka gene pool, one line was bred on the main aboriginal materials of the Uladivka selection, and one line was originated from the Uman breeding materials.

The energy indicators of these lines as possible components (maternal form) of sugar-fodder beet hybrids are given in the Table 1.

The analysis of Table 1 showed that the

**Table 1. Bioethanol yield and energy yield of sterile forms of sugar beet – maternal components of sugar-fodder hybrids**

No.	Breeding samples of sugar beet	Yield of root crops, t/ha	Sugar content of root crops, %	Bioethanol yield, t/ha	Energy yield, GJ/ha
MS forms					
	MS Iv. 24869	36.9	14.4	2.44	61.5
	MS Iv. 24845	36.9	14.6	2.46	58.4
	MS Yalt. MS-7	35.7	13.9	2.26	54.7
	MS Iv. 24404	33.4	14.4	2.20	54.9
	MS Ulad. 28119	28.0	14.5	1.84	46.0
	MS Uman 1212	31.3	15.1	2.14	53.5
	LSD <sub>0.05</sub>	2.2	0.3	0.93	1.4

highest energy yield (calculated data on productive properties) was in the pollen sterile lines MS Iv. 24869 (61.5 GJ/ha) and MS Iv. 2484 (58.4 GJ/ha). These are samples of Ivanivka origin that have the best productivity among the lines.

Among the collection of fodder beet (IACR), which consisted of 50 samples, 23

breeding numbers were selected according to the morphological and biological parameters of the root crop, dry matter content and disease and pest tolerance. There are 4 samples of fodder beet with energy yield exceeding 80.0 GJ/ha: k 13 x 14 (85.0 GJ/ha), k 41 x 42 (87.8 GJ/ha), Halytskyi variety (82.3 GJ/ha) and Lvivskyi Zhovtyi variety (80.8 GJ/ha). They were selec-

ted as pollinator-components for sugar-fodder beet hybrids.

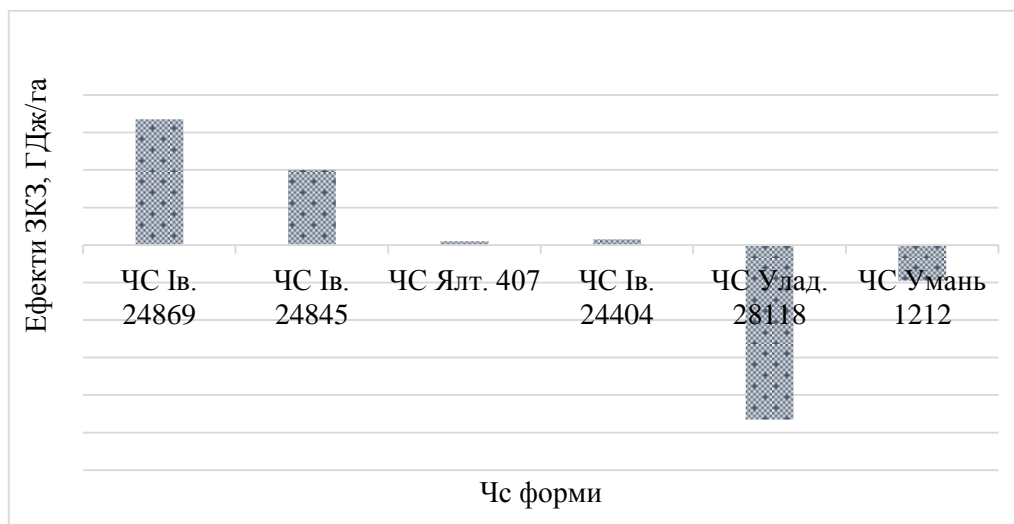
However, the combining ability is more important for hybridization, which was determined by topcrosses conducted to assess the genetic value of these materials.

For sugar-fodder hybrids, the phenotypic manifestation of these traits is significantly influenced not only by environmental conditions, but by the combining value of the components. Therefore, in our research, we selected the best

samples of maternal and paternal forms by combining ability in order to select pairs for promising hybrid combinations that will be used to produce biofuels from renewable sources. A heterotic effect can be expected when the hybridization of well-chosen lines (MS forms and pollinators) characterized by genetic value in terms of bioenergy indicators is carried out.

Fig. 1 shows the effects of the GCA of pollen-sterile lines in terms of energy yield.

The highest energy yield (calculated da-



**Fig. 1. GCA effects on energy yield of pollen-sterile lines of sugar beet – components of sugar-fodder hybrids.**

ta on productive properties) in topcross hybrids was in combinations developed with the pollen-sterile lines MS Iv. 24869 (61.5 GJ/ha) and MS Iv. 24845 (58.4 GJ/ha). The GCA effects of their parental forms were significantly positive and reached 6.7 and 4.0 GJ/ha, respectively.

According to the evaluation of the combining ability of fodder beet pollinators, 10 out of 23 samples with positive GCA effects were selected. Only the best indicators show in Fig. 2, so the sum of GCA effects is not zero. Among the varieties, the lowest positive effect of GCA was in Lada (0.5 GJ/ha), while Halytskyi and Lvivskyi Zhovtyi had high values of 8.0 and 6.5 GJ/ha, respectively. The highest GCA effect was characterized by samples of fodder beet k 13/14 and k 41/2 with high energy yield – 10.7 and 13.5 GJ/ha, respectively.

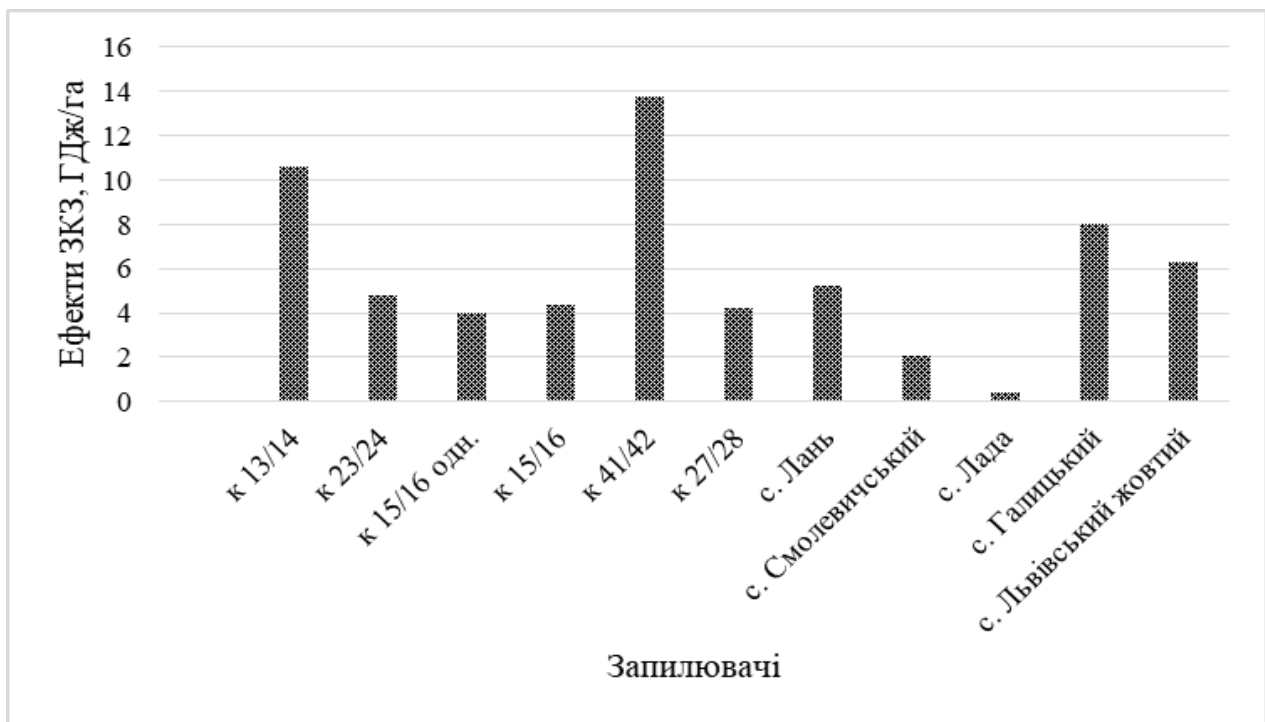
The other best forms of fodder beet with a high positive GCA effect were represented by pollinators k 23/24 and varieties Halyts-

kyi, Lvivskyi Zhovtyi and Lan. Therefore, they were involved in hybridization to develop experimental hybrids suitable for renewable energy purposes at the next stage of breeding.

The genotypic structure of variability of the energy yield trait was determined by analysis of variance for topcross hybrids. It is known that the manifestation of trait is influenced not only by the additive effects of parental lines, but also by their interaction (non-additive variance).

For topcross sugar-fodder hybrids, the influence of the additive component of the genotypic variance of parental forms interpreting the GCA effects was as follows: 30 % for fodder beet and 21 % for testers.

Non-additive interaction, including epistatic effects, is characterized by indicators of specific combining ability (SCA) (Fig. 3). This indicates the importance of pair selection in the formation of sugar-fodder beet hybrids for bioenergy purposes, which will allow to

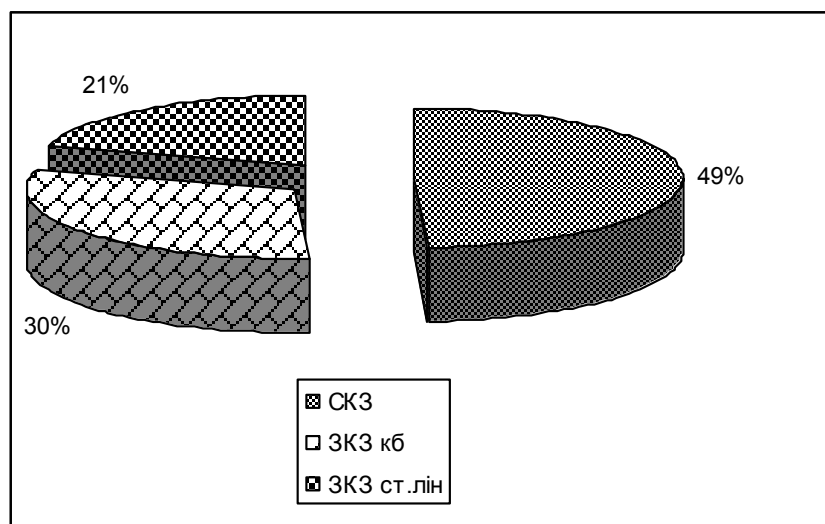


**Fig. 2. GCA effects on energy yield in the best pollinators of fodder beet – components of sugar-fodder hybrids.**

obtain high energy yields.

However, the total influence of valuable additive gene complexes of parental forms (fodder and pollen-sterile sugar beet cultivars) on the trait and the effects of their interaction in a given set of breeding numbers – hybrid components were almost equal as a share of the total genotypic variance – 51 and 49 %, respectively.

At the next stage of the breeding process, hybridization of the six best selected samples of pollen sterile forms (MS forms) and fertile pollinators of fodder beet, which were identified as the best according to the evaluation of their genetic value, was carried out according to the scheme of one-way cyclic crosses in areas of free pollination, where 36 sugar-fodder MS hybrids were developed.



**Fig. 3. Structure of genotypic variability of the energy yield trait for topcross hybrids of sugar-fodder beet.**

The developed sugar-fodder hybrids differed significantly in the resulting trait of energy yield (LSD0.05 = 5.61 GJ/ha). All hybrids based on the crossing of this set of MS forms and

Lvivskiy Zhovtyi variety bred by IACR were characterised by high energy yield, which exceeded 100 GJ/ha, among which the best was the combination of MS Iv. 24869/Lvivskiy Zhovtyi

variety (120.55 GJ/ha) (Table 2). Equally effective for hybridisation with these pollen-sterile forms was the breeding number k 23/24, which was the best pollinator of the combining valuable MS line MS Iv. 24869 of Ivanivka origin (energy yield was 115.01 GJ/ha). However, the first two places in terms of energy yield were taken by hybrids developed on the basis of the combining line

MS Iv. 24869 and fodder beet numbers k 41/42 and k 13/14 (combining-capable pollinators with high GCA). Their energy yield were 123.84 and 125.09 GJ/ha, respectively. Two hybrid combinations based on the genetically valuable line MS Iv. 24845 were developed with pollinators of fodder beet k 13/14 (117.61 GJ/ha) and Lvivskiy Zhovtyi (114.31 GJ/ha).

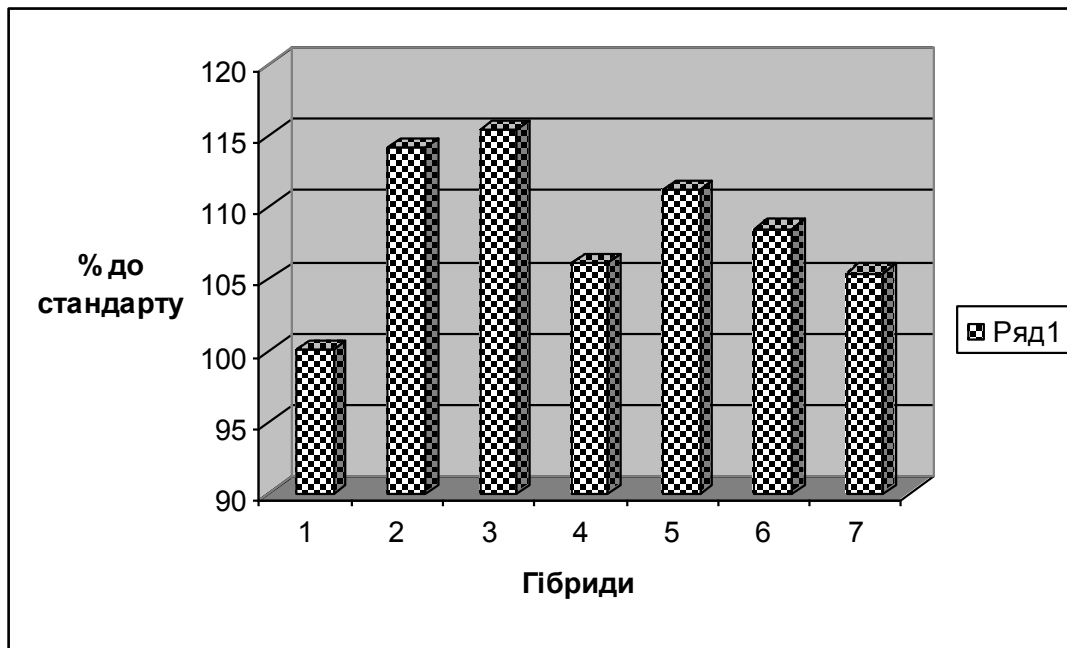
**Table 2. Energy yield of sugar-fodder beet hybrids, GJ/ha**

Components of sugar-fodder hybrids	K 41/42	K 13/14	Halytskyi variety	Lan variety	K 23/24	Lvivskiy Zhovtyi variety
MS Iv. 24869	123.84	125.09	88.76	105.16	115.01	120.55
MS Iv. 24845	95.63	117.61	104.08	101.96	104.44	114.21
MS Yalt. MS-7	104.95	89.32	93.07	105.01	114.8	109.80
MS Iv. 24404	75.21	80.49	98.81	96.78	108.61	113.60
MS Ulad. 28119	76.16	79.99	100.93	98.48	100.74	104.44
MS Uman. 1212	87.08	88.98	94.38	93.81	102.22	105.18

The group standard in terms of energy output was 108.41 GJ/ha.

In terms of the group standard (Fig. 4), the excess ranged from 105.4 to 115.4 %.

The first three places are occupied by hybrids with an energy output of more than 120 GJ/g. We recommend these hybrids for reproduction and for future commercial use.



Note: 1 – Group standard, 2 – MS Iv. 24869/к 41/42; 3 – MS Iv. 24869/к 13/14; 4 – MS Iv. 24869/к 34/24; 5 – MS Iv. 24869/ Lvivskiy Zhovtyi; 6 – MS Iv. 24845/к 13/14; 7 – MS Iv. 24845/Lvivskiy Zhovtyi.

**Fig.4. The best hybrid combinations of sugar and fodder beet in terms of energy yield.**

**Conclusions.** For development of new genotypes of sugar-fodder hybrids for biofuel production, 6 maternal components – MS lines of sugar beet and 23 samples of fodder beet were evaluated for general combining ability

according to the resulting trait of energy yield. Combination-value sugar beet lines MS Iv. 24869 and MS Iv. 24845 of Ivanivka origin and hybrid fodder beet samples k 13/14 and k 41/42, as well as the best fodder beet samples of polli-

nator k 23/24 and Halytskyi, Lvivskyi Zhovtyi and Lan varieties with high positive effect GCA of IACR selection have breeding prospects.

The analysis of the shares of influence of these components showed that the effects of interaction between maternal and paternal forms were predominant in the genotypic variability (49 %) of the resulting trait of energy yield. The significant influence of additive effects of fodder beet as a component in the formation of

quantitative traits in hybrids (30 %) was noted.

Three new genotypes of sugar-fodder hybrids suitable for the biofuel production from renewable sources with energy yield above 120 GJ/ha were developed by the method of combination breeding. These genotypes are MS Iv. 24869/k 41/42; MS Iv. 24869/k 13/14 and MS Iv. 24869/Lvivskyi Zhovtyi variety, which exceed the standard by 14.3, 15.4 and 8.5%, respectively.

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УДК 633.63:631.52

**Корнєєва М. О. Селекція цукрово-кормових гібридів буряків, придатних для виробництва біопалива. Зернові культури. 2022. 6 (2). 13–18.**

*Інститут біоенергетичних культур і цукрових буряків НААН України*

**Актуальність.** Розвиток біоенергетики в Україні потребує вирощування енергетичних культур як відновлювальних джерел енергії. Як сировина для виробництва біопалива селекційну перспективу можуть мати цукрово-кормові гібриди буряки, створені з використанням цінних стерильних форм цукрових і фертильних форм кормових буряків. **Мета.** Створити експериментальні гібриди цукрово-кормових буряків з високим виходом енергії, придатні для отримання альтернативних видів біопалива, і відібрати кращі із них. **Матеріали і методи.** Для створення цукрово-кормових гібридів використано 6 стерильних за пилом ліній цукрових і 23 селекційні номери фертильних кормових буряків. Етапами селекційного процесу були відбір вихідних батьківських ліній, оцінка їх за комбінаційною здатністю та формування гібридів на основі кращих із них. Застосовано метод багатотестерних топкросів та польові випробування експериментальних гібридів. **Результати.** Батьківські компоненти достовірно відрізнялися між собою за виходом енергії, показники якої коливалися у межах 53,5...61,5 GJ/ha (MS форми), а у 4 кращих запилювачів – від 80,0 до 87,8 GJ/ha. За результатами тестерних схрещувань відібрано MS форми ліній цукрових буряків Ів. 24869 та MS Iv. 2484 іванівського походження з достовірно високими ефектами загальної комбінаційної здатності 6,7 та 4,0 GJ/ha та запилювачі сорти кормових буряків Halytskyi і Lvivskyi Zhovtyi – відповідно 8,0 та 6,5 GJ/ha. У генотиповій структурі мінливості ознаки вихід цукру сумарна частка впливу цінних адитивних комплексів генів батьківських форм (51 %) була майже рівнозначною частці неадитивної взаємодії компонентів (49 %). **Висновки.** Методом комбінативної селекції створено три нових генотипи цукрово-кормових гібридів, придатних для виробництва біопалива з відновлювальних джерел, у яких вихід енергії був більшим, ніж 120 GJ/ha. Це генотипи MS Iv. 24869/k 41/42; – MS Iv. 24869/k 13/14 та MS Iv. 24869/ Lvivskyi Zhovtyi з показниками, що перевищують стандарт відно-відно на 14,3, 15,4 та 8,5 %.

**Ключові слова:** біоенергетика, пилкостерильні форми, запилювачі, цукрово-кормові гібриди комбінаційна здатність, вихід енергії