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CREATION AND A BREEDING-GENETIC STUDY OF POLLINATOR LINES – STERILITY MAINTAINERS AND THEIR STERILE COUNTERPARTS IN FODDER BEET BREEDING FOR HETEROSIS

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The article presents results of multi-year research on the creation of pollinators – sterility maintainers (O-type lines) and their sterile counterparts in the breeding of one-sprout fodder beet hybrids. The proportions of pollinators of this type in one-sprout populations of fodder beets of different genetic origins were established. Pollinator lines – sterility maintainers and their sterile counterparts with high basic performance and combining ability for the most important economically valuable characteristics have been created.

Key words: *fodder beets, line, population, inbreeding, heterosis, yield, dry matter content, dry matter output.*

Introduction. The intensification of agricultural development requires a significant improvement of the fodder base of the livestock industry, including by increasing sown areas and expanding the variety assortment of fodder beets. Currently, the majority of domestic and foreign fodder beet varieties and hybrids are multi-sprouted di- and anisoploid populations, which, by their parameters, do not fully meet the today's requirements of agricultural production [1]. Therefore, breeders have set an objective to create qualitatively new, more productive, adapted to environmental conditions, CMS-based one-sprout fodder beet hybrids with a root yield of 100–110 t/ha and a dry matter content of 13–15% [2].

Literature Review and Problem Articulation. With the use of intensive technologies for fodder beet cultivation, the capacity of seeds to give one sprout, along with germinability, acquires great importance. The crop density and uniformity, the root yield, quality and self-cost price and the production profitability depend on this feature to a large extent [3].

Therefore, in view of the topicality of breeding improvement of fodder beet genotypes, it is now necessary to create one-sprout varieties and hybrids with high root yields and increased contents of dry matter, carbohydrates and mineral salts. They are supposed to be plastic under different growing conditions and various doses of organic and mineral fertilizers as well as resistant to negative effects of environmental biotic and abiotic factors [2, 4].

Further progress in this direction of research is impossible without constant enrichment of the crop gene pool and expansion of the limits of its genetic variability. Therefore, enrichment of starting material collections and formation of a gene bank of practically significant quantitative and qualitative breeding/genetic traits is a primary objective of the practical breeding of fodder beets [5].

The orientation of breeding/genetic studies towards interline hybridization determines the need to create combinable CMS-based parental lines of hybrids [6, 7]. The combining ability for economically valuable characteristics is genetically determined and, hence, inherited by offspring [8, 9].

In practice, designs of classical inbreeding and its moderate forms (sister crossing) are used to develop lines. Fodder beets are a cross-pollinated crop, so the creation of lines requires isolation of plants and their forced self-pollination, which are quite complex processes. It was revealed that fodder beets, being generally self-sterile plants, became self-compatible under certain conditions [10]. S.D. Orlov reported that the average number of plants capable of self-pollination in variety populations of one-sprout fodder beets ranged 2.5% to 18.1% [11]. Plants set seeds in various quantities and of various qualities. However, in many cases, there were to few seeds for further breeding. Therefore, in order to preserve valuable plant genotypes, their effective reproduction and evaluation, the moderate form of inbreeding, sister crossing, is used studies [6, 12].

The creation of high-yielding one-sprout fodder beet hybrids is a complex breeding process, which requires, first of all, investigations of inheritance patterns of the most important breeding/genetic traits and economically valuable characteristics, their correlations and variability [13, 14].

The development of new methods of creating sterility-based parental components of one-sprout fodder beet hybrids (O-type lines and their sterile counterparts, multi-sprout pollinators) enables reducing effects of harmful recessive genes and increasing the number of valuable dominant alleles in the genotype [3, 15]. These important methods improving polygenic traits of fodder beets include recurrent breeding approaches, which nowadays are successfully used in almost all field crops. The use of fodder beet recombinant materials in breeding contributes to the creation of new plant genotypes – pollinators – sterility maintainers, their sterile counterparts and multi-sprout diploid pollinators of different genetic structures, – making more effective use of various combinative variations, accumulation of desirable genes of traits that need to be improved, expansion of the genetic basis of plants, and reduction in the negative correlation between the root yield and dry matter content, etc. possible [16, 17]. This will allow for generation of valuable starting material – parental forms for the breeding of sterility-based one-sprout fodder beet hybrids.

The role of genetic features of modern one-sprout fodder beet hybrids in the industry intensification is quite significant. To maximize the heterosis phenomenon use, it is quite relevant to evaluate parental components of crossbreeding for performance as well as hybridizing and reproductive capabilities [1, 18].

Nowadays, there is a need to analyze integral genetic systems that control several traits in one genotype. Special attention is paid to associative selection based on the understanding of the genotype as a whole integrated system. All these will contribute to the creation and further targeted use of new starting material of fodder beets to generate highly productive crossing combinations, which is a pre-requisite for boosting the efficiency of recombinant breeding [2, 8]. The use of combinable lines - Owen type sterility maintainers (O-type) is a traditional way of creating one-sprout male-sterile forms of fodder beets. They play a key role in the creation of CMS-based heterotic hybrids [11, 12]. However, the search for new plant genotypes, pollinators – sterility maintainers, a rather long process and requires considerable breeding work with starting material.

The Study Purpose was to create pollinator lines – sterility maintainers and their sterile counterparts and to study their breeding and genetic features for the development of parental components of CMS-based one-sprout fodder beet hybrids.

Materials and Methods. The study was carried out at the Tobacco Research Station of the National Scientific Center "IA NAAS" (Cherkaska Oblast, Uman) in 2013–2021. Four diploid one-sprout fodder beet populations of hybrid origin were taken as the starting material. Fodder beet lines were created by inbreeding. Analyzing crossings were carried out under paired coarse calico bags. The experiments were replicated three times; the record plot area was 10.8 m^2. The plots were arranged randomly. Breeding accessions were tested in accordance with a method developed by scientists of the Institute of Bioenergy Crops and Sugar Beet of NAAS [19]. Slaviia, a multi-sprout fodder beet, was used as the check variety. The specific combining ability (SCA) was evaluated by V.K. Savchenko's method [20]. Data were statistically processed, as B.A. Dospekhov recommended [21].

Results and Discussion. Cytoplasmic male sterility belongs to the phenomena caused by non-chromosomal inheritance. Its inheritance cannot be explained by H. Mendel's laws. To maintain it, special pollinators (O-type) are needed; their genotypes have the "x" and "z" recessive factors in a homozygous state and N-cytoplasm, which determines their normal pollen-forming ability. Such pollinators do not differ phenotypically from ordinary, fertile plants with these factors in a heterozygous or in a dominant state [15, 16].

Therefore, it is quite difficult to identify fodder plants that would completely fix the pollen sterility in beet populations. In practical breeding, to select sterility maintainers (O-type), controlled crossings of completely sterile sugar beet plants with one-sprout fertile fodder beet plants (candidates for O-type pollinators) followed by sterility analysis of the obtained CMS-offspring were used. It should be noted that the main selection criteria for sugar beet CMS-lines intended for hybridization were a low sugar content, oval-conical roots and incomplete penetration of roots into the soil. According to the pollen sterility indicators in the offspring plants from these breeding forms, the genetic structure of the candidates for pollinators - O-type sterility maintainers was determined for the "x" and "z" nuclear genes and pollinators carrying them in a recessive homozygous state were selected.

At the first stages breeding, the sterility degree was determined in a limited number of male-sterile offspring plants (30–45) for pre-evaluation of the genotypes of candidates for O-type pollinators. This allowed increasing the number of analyzing crosses and, accordingly, the sample of candidates for O-type pollinators, the genotypes of which were investigated. To statistically significantly assess the sterility degree in the CMS-offspring with ≥ 95% portion of completely sterile plants, at least 350–400 plants were analyzed.

The results indicate a rather high portion (3.7–11.3%) of pollinators – sterility maintainers (genotype Nxxzz) among the one-sprout fodder beet hybrids bred in Uman (Table 1).

Table 1

Presence of pollinators – Sterility Maintainers among the one-sprout fodder beet hybrids of different genetic origins, 2015–2017

Pedigree designation	Number of crossings	Number of analyzed plants	Percentage of sterility maintainers, %
KZ-1507 2xmm	111	4662	10.8
KT-7105 2xmm	87	4881	11.3
IM-3319 2xmm	123	6396	4.2
ST-4514 2xmm	102	4896	3.7
Mean	106	5209	7.5

The mean across all the initial accessions was 7.5%. The highest percentages of pollinators - Owen type (O-type) sterility maintainers were recorded for one-sprout hybrids KT-7105 2xmm and KZ-1507 2xmm. This is attributed to the fact that O-type sugar beet lines were used for their creation at pre-breeding stages to increase the penetrance of the "x" and "z" genes in the offspring.

Assessment of pollen sterility and seed bearer fertility in the CMS-analogues of the O-type fodder beet lines derived from different initial forms indicates a high breeding/genetic quality of the obtained pollinators (Table 2).

Taking into account the percentages of plants with type I completely sterile or semi-sterile pollen, the mean sterility across the CMS-analogues of the O-type lines of different genetic origins was 99.6%. The highest percentage of plants with completely sterile pollen was noted for the sterile counterparts of the O-type lines, which were originated from initial accessions IM-3319 2xmm and KZ-1507 2xmm (99.1% and 97.0%, respectively). The highest percentage of one-sprout seeds was intrinsic to the sterile counterparts of the O-type lines, which were originated from hybrid accessions KZ-1507 2xmm and KT-7105 2xmm. The percentage of seed bearers with 1-1-1 fertility type was 64.2% and 57.5%, respectively.

Table 2

Characterization of the CMS-analogues of the O-type fodder beet lines of different genetic origins by pollen sterility and type of seed bearer fertility, 2018–2020

Origin of O-type pollinators	Number of analyzed CMS-lines.	Number of analyzed plants.	Pollen sterility, %			Type of seed bearer fertility, %		
			completely sterile	type i semi-sterile	type ii semi-sterile	1-1-1	2-1-1	2-2-2
KZ – 1507 2xmm	12	4440	97.0	2.6	0.4	64.2	35.8	0
KT – 7105 2xmm	10	3850	96.0	3.4	0.6	57.5	42.5	0
IM – 3319 2xmm	5	1930	99.1	0.9	0	33.5	66.5	0
ST – 4514 2xmm	4	1540	95.2	4.1	0.7	25.9	74.1	0
Mean	8	2940	96.8	2.8	0.4	45.3	54.7	0

The selection of O-type lines and their sterile counterparts, especially in fodder beets, is a complicated process that combines a complex approach to the selection of the best plant genotypes. Of 31 pollinators – sterility maintainers, with due account for optimal combinations of the most important breeding/genetic traits and economically valuable characteristics, 15 best O-type lines were selected for further breeding to develop parental components of CMS-based experimental hybrids (Table 3).

Table 3

Characterization of the best fodder beet pollinator lines – Sterility Maintainers by breeding and genetic traits, 2019–2021

Breeding ID	Pollen fertility, %	Percentage of one-sprout seeds, %	CMS fixing, %	Root shape	Penetration of roots into the soil
OT KZ-1507/5	100	98.6	98.9	Oval	1/3
OT KZ-1507/29	100	99.2	98.7	-//-	1/3
OT KZ-1507/33	100	97.5	97.6	-//-	1/3
OT KZ-1507/41	100	97.9	100	-//-	1/3
OT KT-7105/7	100	99.3	96.2	-//-	1/3
OT KT-7105/25	100	98.2	96.8	-//-	1/3–1/2
OT KT-7105/34	100	98.0	97.1	-//-	1/3
OT IM-3319/3	99.1	97.2	100	-//-	1/3
OT IM-3319/13	100	96.5	99.0	-//-	1/3
OT IM-3319/16	100	96.4	99.2	-//-	1/3–1/2
OT IM-3319/34	100	97.2	98.6	-//-	1/3
OT IM-3319/49	99.0	96.4	98.6	-//-	1/3
OT ST-4514/11	100	97.4	96.9	-//-	1/3
OT ST-4514/27	99.0	97.3	97.8	-//-	1/3
OT ST-4514/39	100	97.0	96.4	-//-	1/3

They were characterized by pollen fertility of 99.0–100.0%; the percentage of one-sprout seeds amounted to 96.4–99.3%; CMS fixing reached 96.2–100%.

It should be remarked that these fodder beet pollinators, in addition to high fixing ability of pollen sterility and one-sprout seeds, were noticeable for oval roots and their slight penetration into the soil. The last two characteristics are of especial importance in fodder beet breeding, as they determine their high productivity and low energy costs for digging out roots from the soil.

The next stage of our study was to evaluate the basic performance of the sterile counterparts of the above-mentioned pollinator lines – sterility maintainers (Table 4).

Analysis of the results showed that the beetroot yields of the majority of the fodder beet CMS-lines were lower that that of the check variety. CMS IM-3319/16, CMS IM-3319/34 and CMS IM-3319/49 were the only lines that yielded at the level of the check variety (80.9–83.6 t/ha), which is attributed primarily to their genetic origin. The dry matter content in beetroots of lines CMS ST-4514/27 and CMS ST-4514/39 significantly exceeded the check variety's value (14.7% and 14.8%, respectively); in the others lines, this parameter was similar to that of the check variety. As to the dry matter output, except for CMS KT-7105/7, CMS ST-4514/27, CMS IM-3319/34 and CMS IM-3319/49, most lines were inferior to the check variety.

Table 4

Performance of the Sterile Counterparts of the best fodder beet pollinator lines – Sterility Maintainers in the 2019–2021 trials

Breeding ID	Beetroot yield, t/ha	Dry matter content, %	Dry matter output, t/ha	Related to the check variety, %		
				beetroot yield	dry matter content	dry matter output
CMS KZ-507/5	78.9	14.4	11.4	93.7	101.4	95.8
CMS KZ-1507/29	77.2	14.3	11.0	91.7	100.7	92.4
CMS KZ-1507/33	76.8	14.5	11.1	91.2	102.1	93.3
CMS KZ-1507/41	75.8	14.2	10.8	90.0	100.0	90.8
CMS KT-7105/7	79.6	14.5	11.5	94.5	102.1	96.6
CMS KT-7105/25	80.2	14.2	11.4	95.2	100.0	95.8
CMS KT-7105/34	78.2	14.5	11.3	92.9	102.1	95.0
CMS IM-3319/3	80.3	14.2	11.4	95.4	100.0	95.8
CMS IM-3319/13	81.4	14.0	11.4	96.7	98.6	95.8
CMS IM-3319/16	80.9	14.0	11.3	96.1	98.6	95.0
CMS IM-3319/34	83.6	14.4	12.0	99.3	101.4	100.8
CMS IM-3319/49	82.8	14.1	11.7	98.3	99.3	98.3
CMS ST-4514/11	78.1	14.5	11.3	92.8	102.1	95.0
CMS ST-4514/27	77.9	14.7	11.5	92.5	103.5	96.6
CMS ST-4514/39	77.2	14.8	11.4	91.7	104.2	95.8
$\bar{x}$	79.3	14.4	11.4	94.1	101.1	95.5
Slaviia (check variety)	84.2	14.2	11.9	–	–	–
$LSD_{0.05}$	3.5	0.46	0.43	–	–	–

In the breeding of CMS-based high-yielding one-sprout fodder beet hybrids, in addition to the previous breeding/genetic traits, the hybridization potential of crossbreeding components plays a particularly important role. Taking into account the fact that the initial populations of fodder beets were characterized by high general combining ability (GCA) and that this trait is hereditary, we tested the best CMS lines only for specific combining ability (SCA). Comparison of the hybridization potentials of some lines in this experiment is of undeniable interest. For SCA, this can easily be done by comparing hybridization effects. Comparison of the SCA of a line - parent of a series of hybrids with the SCA of another line – parent of a different group of crossing combinations is more complicated. This can be done only by calculating variances for the SCA of each line (Table 5).

Table 5

SCA variances of the best CMS fodder beet lines by root yield and dry matter content, 2019–2021

Breeding ID	Beetroot yield	Dry matter content
CMS KZ-1507/5	1.23	0.179
CMS KZ-1507/29	2.15	0.105
CMS KZ-1507/33	2.41	0.069
CMS KZ-1507/41	3.17	0.131
CMS KT-7105/7	3.09	0.186
CMS KT-7105/25	3.04	0.115
CMS KT-7105/34	2.71	0.098
CMS IM-3319/3	4.35	0.147
CMS IM-3319/13	3.17	0.154
CMS IM-3319/16	3.05	0.112
CMS IM-3319/34	4.23	0.131
CMS IM-3319/49	5.17	0.124
CMS ST-4514/11	3.11	0.133
CMS ST-4514/27	1.77	0.181
CMS ST-4514/39	2.05	0.127

As already mentioned, the general combining ability is a hereditary trait, and the CMS lines created were characterized by its high levels. However, this level is differently achieved by each line due to differences in the variances of the specific combining ability. Low SCA variances for the beetroot yield in lines CMS KZ-1507/5, CMS ST-4514/27, CMS KZ-1507/29, CMS ST-4514/39, and CMS KZ-1507/33 and for the dry matter content in lines CMS KZ-1507/33, CMS KT-7105/34, CMS KZ-1507/29, CMS KT-7105/25, and CMS IM-3319/16 indicate that all the crossing combinations originated from these lines showed consistently strong expression of the corresponding traits. At the same time, the SCA variances are high for the beetroot yield in lines CMS IM-3319/49, CMS IM-3319/3, CMS IM-3319/34, CMS IM-3319/13, and CMS KZ-1507/41 and for the dry matter content in lines CMS KT-7105/7, CMS ST-4514/27, CMS KZ-1507/5, and CMS IM-3319/3, indicating that strong expression of the traits was due to specific combinations, which were significantly stronger than a medium level that could be expected, and, vice versa, due to combinations with expression of the corresponding traits, which was significantly weaker than the medium level. Therefore, these features of breeding materials should be taken into account when selecting crossbreeding components. In general, comprehensive assessments of basic performance, combining ability, pollen sterility-fertility, seed bearer fertility, resistance to negative effects of biotic and abiotic factors of the environment are a vital factor in their targeted selection to develop CMS-based one-sprout fodder beet hybrids with specified performance parameters.

Conclusions. We found that the portion of pollinators – sterility maintainers in one-sprout populations of fodder beets of different genetic origins was 3.7–11.3%. Fifteen combinable O-type lines with pollen sterility fixing of 96.2–100% and percentage of one-sprout seeds of 96.4–99.3% have been created. Their sterile counterparts have been obtained. The created breeding accessions are a valuable starting material for the selection of parental components and generation of highly productive CMS-based one-sprout fodder beet hybrids.

Список використаних джерел

1. Зубенко В. Ф., Роїк М. В., Іващенко О. О., Гізбулін Н. Г. та ін. Буряківництво. Проблеми інтенсифікації та ресурсозбереження / за ред. В. Ф. Зубенка. Київ: НВП ТОВ "Альфа-стевія ЛТД", 2007. 486 с.
2. Роїк М. В. Буряки. Київ: XXI, 2001. 320 с.
3. Слівченко А. М., Яценко О. А., Моргун А. В., Слівченко О. А., Жученко О. І., Собченко Л. К. Селекція однонасінних кормових буряків. Збірник наукових праць ІЦБ УААН, 2005. Вип. 8. С. 244–249.
4. Adhikari P., Araya H., Aruna G. et al. System of crop intensification for more productive, resource-conserving, climate-resilient, and sustainable agriculture: experience with diverse crops in varying agroecologies. International journal of agricultural sustainability. 2018, Vol. 16 (1). P. 1–28. DOI: https://doi.org/10.1080/14735903. 2017.1402504.
5. Frese L., Desprez B., Ziegler D. Potential of genetic resources and breeding strategies for base-broadening in Beta. Broadening the genetic base of crop production/ H. D Cooper, C. Spillane, T. Hodgkin. (Eds.). Wallingford, UK: Cabi Publishing, 2001. P. 295–309. DOI: https://doi.org/10.1079/9780851994116.0295.
6. Роїк М. В., Орлов С. Д., Джігіріс Л. А., Шараєнко О. М. Нові методи створення компонентів гібридів кормових буряків на ЧС основі. Збірник наукових праць ІЦБ УААН. 2005. Вип. 8. С. 238–243.
7. Дубчак О. В. Створення експериментальних гібридів кормових гібридів на стерильній основі та оцінка їх продуктивності. Збірник наукових праць БНАУ МАПУ. 2010. Вип. 3 (74). С. 43–46.
8. Fasahat P., Rajabi A., Rad J. M. et al. Principles and utilization of combining ability in plant breeding. Biom Biostat Int J, 2016. Vol. 4 (1). P. 1–22. DOI: https://doi.org/10.15406/bbij.2016.04.00085.
9. Орлов С. Д., Костогриз Л. А., Бровко С. М., Мілієнко М. В. Комбінаційна здатність у селекції кормових буряків. Наукові праці Інституту біоенергетичних культур і цукрових буряків. 2012. Вип. 15. С. 264–267.
10. Шевцов І. А., Чугункова Т. В. Буряки цукрові, кормові, столові. Київ: Логос, 2001. 128 с.
11. Орлов С. Д. Вихідні матеріали кормових буряків різного рівня геному, їх використання у селекції на гетерозис. Збірник наукових праць Інституту цукрових буряків УААН. 2008. Вип. 10. С. 118–122.
12. Поліщук Т В., Баланюк Л. О., Татарчук В. М. Методи створення та шляхи використання лінійних матеріалів одноросткових кормових буряків у селекції на гетерозис. Збірник наук. праць Уманського НУС. 2014. Вип.86. С. 67–72.
13. Мілієнко М. В Вивчення господарсько цінних та морфологічних ознак коренеплодів вихідних форм та гібридів буряку кормового (*Beta vulgaris* L. *subsp. vulgaris var. crassa*). Сортовивчення та охорона прав на сорти рослин. 2012. № 2. С. 62–66.
14. Рибак Д. А., Фомічова А. М., Ярош Ю. М. Селекція і насінництво кормового буряка в Україні. Вісник аграрної науки. 1998. № 8. С. 39–43.
15. Генетические основы селекции растений. Т.2. Частная селекция растений/ науч. ред. А. В. Кильчевский, Л. В. Хотылева. Минск, 2010. 579 с.
16. Корниенко А. В., Моргун А. В., Труш С. Г. Селекция свеклы на гетерозис (*Beta vulgaris* L.). Воронеж, 2007. 255 с.
17. Дубчак О. В., Орлов С. Д. Рекомбінування господарсько-цінних ознак у кормових буряків. Цукрові буряки. 2015. Вип. 5 (107). С. 4–7.
18. Labroo M. R., Studer A. J., Rutkoski J. E. Heterosis and Hybrid Crop Breeding: A Multidisciplinary Review. Front. Genet. 2021. Vol. 12. 643761. DOI: https://doi.org/10.3389/fgene.2021.643761.
19. Роїк М. В., Гізбуллін Н. Г., Сінченко В. М., Присяжнюк О. І. та ін. Методики проведення досліджень у буряківництві /за ред. М. В. Роїка та Н. Г. Гізбулліна. Київ: ФОП Корзун Д. Ю., 2014. С. 24–345.

20. Савченко В. К. Многоцелевой метод количественной оценки комбинационной способности в селекции на гетерозис. Генетика. 1978. Т. 14. № 5. С. 793–804.
21. Доспехов Б. А. Методика полевого опыта с основами статистической обработки результатов исследований. Москва: Агропромиздат, 1985. 351 с.

References

1. Zubenko V.F., Royik M.V., Ivashchenko O.O., Hizbulin N.H. et al. Beet growing. Problems of intensification and resource saving. Zubenko VF, ed. Kyiv: Alfa-steviia LTD, 2007. 486 p.
2. Royik M.V. Beets. Kyiv: XXI, 2001. 320 p.
3. Slivchenko A.M., Yatsenko O.A., Morhun A.V., Slivchenko O.A., Zhuchenko O.I., Sobchenko L.K. One-seed fodder beet breeding. Zbirnyk Naukovykh Prats Instytutu Tsukrovykh Buriakiv UAAN. 2005; 8: 244–249.
4. Adhikari P., Araya H., Aruna G. et al. System of crop intensification for more productive, resource-conserving, climate-resilient, and sustainable agriculture: experience with diverse crops in varying agroecologies. International journal of agricultural sustainability. 2018; 16 (1): 1–28. DOI: https://doi.org/10.1080/14735903. 2017.1402504.
5. Frese L., Desprez B., Ziegler D. Potential of genetic resources and breeding strategies for base-broadening in Beta. In: Cooper HD, Spillane C, Hodgkin T, editors. Broadening the genetic base of crop production. Wallingford, UK: Cabi Publishing, 2001. P. 295–309. DOI: https://doi.org/10.1079/9780851994116.0295.
6. Royik M.V., Orlov S.D., Dzhihiris L.A., Sharaienko O.M. New methods of creating components of MS-based fodder beet hybrids. Zbirnyk Naukovykh Prats Instytutu Tsukrovykh Buriakiv UAAN. 2005; 8: 238–242.
7. Dubchak O.V. Creation of sterility-based experimental fodder hybrids and evaluation of their performance. Zbirnyk Naukovykh Prats BNAU MAPU. 2010; 3 (74): 43–46.
8. Fasahat P., Rajabi A., Rad J.M. et al. Principles and utilization of combining ability in plant breeding. Biom Biostat Int J. 2016; 4 (1): 1–22. DOI: https://doi.org/10.15406/bbij.2016.04.00085.
9. Orlov S.D., Kostohryz L.A., Brovko S.M., Miliienko M.V. Combining ability in fodder beet breeding. Naukovi Pratsi Instytutu Bioenerhetychnykh Kultur i Tsukrovykh Buriakiv. 2012; 15: 264–267.
10. Shevtsov I.A., Chuhunkova T.V. Sugar, fodder and table beets. Kyiv: Logos, 2001. 128 p.
11. Orlov SD. Starting materials of fodder beets of different genome levels, their use in breeding for heterosis. Zbirnyk Naukovykh Prats Instytutu Tsukrovykh Buriakiv UAAN. 2008; 10: 118–122.
12. Polishchuk T.V., Balaniuk L.O., Tatarchuk V.M. Methods of creation and ways of using one-sprout fodder beet lines in breeding for heterosis. Zbirnyk Naukovykh Prats Umanskoho NUS. 2014; 86: 67–72.
13. Miliienko M.V. Study of economically valuable and morphological features of roots of fodder beet (*Beta vulgaris* L. *subsp. vulgaris var. crassa*) initial forms and hybrids. Sortovyvchennia ta Okhorona Prav na Sorty Roslyn. 2012; 2: 62–66.
14. Rybak D.A., Fomichova A.M., Yarosh Yu.M. Fodder beet breeding and seed production in Ukraine. Visnyk Ahrarnoyi Nauky. 1998; 8: 39–43.
15. Genetic basics of plant breeding. Vol. 2. Special breeding of plants. Kilchevskiy A.V., Khotylyova L.V., eds. Minsk, 2010. 579 p.
16. Korniyenko A.V., Morgun A.V., Trush S.H. Beet (*Beta vulgaris* L.) breeding for heterosis. Voronezh, 2007. 255 p.
17. Dubchak O.V., Orlov S.D. Recombination of economically valuable traits in fodder beets. Tsukrovi Buriaky. 2015; 5 (107): 4–7.
18. Labroo M.R., Studer AJ., Rutkoski JE. Heterosis and Hybrid Crop Breeding: A Multidisciplinary Review. Front. Genet. 2021; 12: 643761. DOI: https://doi.org/10.3389/fgene.2021.643761.

19. Royik M.V., Hisbullin N.H., Sinchenko V.M., Prysiazhnyuk O.I. et al. Methods of research in beet growing. Royik M.V., Hizbullin N.H., eds. Kyiv: Private Enterprise Korzun DYu., 2014. 374 p.
20. Savchenko V.K. A multipurpose method for quantitative assessment of combining ability in breeding for heterosis. Genetika. 1978; 14 (5): 793–804.
21. Dospekhov B.A. Methods of field experimentation with basics of statistical processing of data. Moscow: Agropromizdat, 1985. 351 p.

СТВОРЕННЯ ТА СЕЛЕКЦІЙНО-ГЕНЕТИЧНЕ ВИВЧЕННЯ ЛІНІЙ ЗАПИЛЮВАЧІВ-ЗАКРІПЛЮВАЧІВ СТЕРИЛЬНОСТІ ТА ЇХ АНАЛОГІВ З ЦЧС В СЕЛЕКЦІЇ БУРЯКІВ КОРМОВИХ НА ГЕТЕРОЗИС

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Мета досліджень – створення та селекційно-генетичне вивчення ліній запилювачів-закріплювачів стерильності та їх аналогів з цитоплазматичною чоловічою стерильністю (ЦЧС) для формування батьківських компонентів однорасткових гібридів буряків кормових на ЦЧС основі.

Матеріали і методика досліджень. Дослідження проводилися на Дослідній станції тютюнництва ННЦ «ІЗ НААН» у 2013–2021 рр. (Черкаська обл., м. Умань). Вихідним матеріалом слугували чотири диплоїдні однорасткові популяції буряків кормових гібридного походження. Створення лінійних матеріалів буряків кормових здійснено з використанням методу інбридингу. Аналізуючі схрещування проведено під парними бязевими ізоляторами. Сортовипробування селекційних зразків виконано за методикою, розробленою науковцями Інституту біоенергетичних культур і цукрових буряків НААН.

Обговорення результатів. Результати досліджень свідчать про досить високу частоту стрічання запилювачів-закріплювачів стерильності у гібридних матеріалах однорасткових буряків кормових уманської селекції. Середній показник за всіма вихідними зразками становив 7,5 %. Найвищою наявністю запилювачів-закріплювачів стерильності Оуенівського типу характеризувалися однорасткові гібридні матеріали КТ-7105 2xmm і КЗ-1507 2xmm. Високий рівень стерильності пилку мали ЦЧС аналоги ліній О-типу, отримані на основі вихідних зразків IM-3319 2xmm і КЗ-1507 2xmm (99,1 % і 97,0 %). Найвища однорастковість насіння була притаманна ЦЧС аналогам ліній О типу, створеним на основі гібридних матеріалів КЗ-1507 2xmm і КТ-7105 2xmm. Відібрано 15 кращих ліній О-типу для подальшого селекційного процесу з формування батьківських компонентів експериментальних гібридів на ЦЧС основі. Аналіз результатів досліджень свідчить, що врожайність коренеплодів більшості ЦЧС ліній буряків кормових була нижчою стандарту. Лише лінії ЦЧС IM-3319/16, ЦЧС IM-3319/34 і ЦЧС IM-3319/49 мали цей показник на рівні стандарту, що обумовлено насамперед їх генетичним походженням. За вмістом сухої речовини в коренеплодах лише лінії ЦЧС СТ-4514/27, ЦЧС СТ-4514/39 істотно переважали стандарт, показники інших були на рівні стандарту. За збором сухої речовини, окрім ЦЧС КТ-7105/7, ЦЧС IM-3319/34 і ЦЧС IM-3319/49 більшість ліній поступалися стандарту.

Висновки. За результатами досліджень установлено, що частка запилювачів-закріплювачів ЦЧС в однорасткових популяціях буряків кормових різного генетичного походження становить 3,7–11,3 %. Створено 15 комбінаційно-здатних ліній О-типу з ступенем закріплення стерильності пилку – 96,2–100 % і однорастковістю насіння – 96,4–99,3 %. Отримано їх аналоги з ЦЧС. Створені селекційні зразки є цінним вихідним

матеріалом для добору батьківських компонентів та формування високопродуктивних однoросткових гібридів буряків кормових на ЦЧС основі.

Ключові слова: *буряки кормові, лінія, популяція, інбридинг, гетерозис, урожайність, вміст сухої речовини, збір сухої речовини.*

CREATION AND A BREEDING-GENETIC STUDY OF POLLINATOR LINES – STERILITY MAINTAINERS AND THEIR STERILE COUNTERPARTS IN FODDER BEET BREEDING FOR HETEROSIS

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Purpose. To create pollinator lines – sterility maintainers and their cytoplasmic male sterile counterparts and to study their breeding and genetic features for the development of parental components of CMS-based one-sprout fodder beet hybrids.

Materials and Methods. The study was carried out at the Tobacco Research Station of the National Scientific Center "IA NAAS" (Cherkaska Oblast, Uman) in 2013–2021. Four diploid one-sprout fodder beet populations of hybrid origin were taken as the starting material. Fodder beet lines were created by inbreeding. Analyzing crossings were carried out under paired coarse calico bags. Breeding accessions were tested in accordance with a method developed by scientists of the Institute of Bioenergy Crops and Sugar Beet of NAAS.

Results and Discussion. The results indicate a fairly high frequency of pollinators – sterility maintainers among the one-sprout fodder beet hybrids bred in Uman. The mean across all the initial accessions was 7.5%. One-sprout hybrids KT-7105 2xmm and KZ-1507 2xmm demonstrated the highest incidence Owen type pollinators – sterility maintainers. A high level of pollen sterility was intrinsic to the sterile counterparts of the O-type lines derived from the initial accessions IM-3319 2xmm and KZ-1507 2xmm (99.1% and 97.0%, respectively). The highest percentage of one-sprout seeds was recorded for the sterile counterparts of the O-type lines derived from hybrid accessions KZ-1507 2xmm and KT-7105 2xmm. Fifteen best O-type lines have been selected for further breeding to obtain parental components of CMS-based experimental hybrids. Analysis showed that the beetroot yields of the majority of the CMS fodder beet lines were lower than that of the check variety. CMS IM-3319/16, CMS IM-3319/34 and CMS IM-3319/49 were the only lines that yielded at the level of the check variety (80.9–83.6 t/ha), which is attributed primarily to their genetic origin. As to the dry matter content in beetroots, only lines CMS ST-4514/27 and CMS ST-4514/39 significantly exceeded the check variety; the values of the others were similar to that of the check variety. In terms of the dry matter output, except for CMS KT-7105/7, CMS IM-3319/34 and CMS IM-3319/49, most lines were inferior to the check variety.

Conclusions. We found that the portion of pollinators – sterility maintainers in one-sprout populations of fodder beets of different genetic origins was 3.7–11.3%. Fifteen combinable O-type lines with pollen sterility fixing of 96.2–100% and percentage of one-sprout seeds of 96.4–99.3% have been created. Their sterile counterparts have been obtained. The created breeding accessions are a valuable starting material for the selection of parental components and generation of highly productive CMS-based one-sprout fodder beet hybrids.

Key words*: fodder beets, line, population, inbreeding, heterosis, yield, dry matter content, dry matter output.*