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# INHERITING THE RESISTANCE OF SUNFLOWER TO TRIBENURON METHYL UNDER INSUFFICIENT HUMIDIFICATION IN THE SOUTHERN STEPPE OF UKRAINE

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**Aim.** This study aimed to investigate the inheritance of resistance to sulfonylurea herbicides in sunflower under conditions of insufficient humidification in the southern Steppe of Ukraine. **Methods.** Isolation, castration, hybridization, herbicide application (Granstar Pro 75 % w.g., containing tribenuron methyl as the active substance (a.s.)), evaluation of herbicide resistance, and statistical analysis of the acquired data. **Results.** The investigation into the inheritance of resistance to sulfonylurea herbicides involved the utilization of both resistant (SURES-1, OS 1099 V, OS 2017 V) and non-resistant (Od 1002 B, Od 1318 V, OS 1295 V) sunflower genotypes. Through crossing, four F<sub>1</sub> hybrid combinations were generated, namely OS 2017 V × OS 1099 V, SURES-1 × Od 1002 B, SURES-1 × Od 1318 V, and Od 1318 V × OS 1295 V. Subsequent treatment of F<sub>1</sub> plants with the herbicide Granstar Pro 75 % w.g. revealed that three combinations (OS 2017 V × OS 1099 V, SURES-1 × Od 1002 B, SURES-1 × Od 1318 V) exhibited complete resistance to the herbicide. In the second generation, following herbicide treatment, the hybrid combinations SURES-1 × Od 1002 B and SURES-1 × Od 1318 V displayed segregation into resistant and non-resistant plants. Conversely, the plants in the combination OS 2017 V × OS 1099 V maintained complete resistance to the herbicidal effects. **Conclusions.** The investigation, conducted in the challenging climatic conditions of the southern Steppe of Ukraine, demonstrated complete resistance to sulfonylurea herbicides in three hybrid combinations of both F<sub>1</sub> and F<sub>2</sub> generations. Notably, the combination OS 2017 V × OS 1099 V exhibited uniform resistance throughout the second generation, devoid of segregation. Moreover, the results of F<sub>2</sub> segregation analysis in the SURES-1 × Od 1002 B and SURES-1 × Od 1318 V populations indicated that resistance to tribenuron methyl is primarily governed by the presence of a dominant gene allele. These findings offer valuable insights for the development of sunflower hybrids with enhanced herbicide resistance, particularly in regions with adverse climatic conditions.

**Key words:** sunflower, resistance to herbicides, sulfonylurea, tribenuron methyl, inheritance, gene *AHAS*.

**DOI:**

## INTRODUCTION

The primary objective of crop breeding is to develop new varieties and hybrids while enhancing the existing ones. The ever-increasing global population, diminishing arable land, the impacts of climate change, and challenges related to water availability underscore the urgent need to augment food production by improving the yield potential of cultivated crops. This improvement should not be limited to the acquisition of novel,

more productive genotypes but should also encompass the development of innovative cultivation techniques. The breeding of plants for resistance to herbicides is a pivotal facet of this endeavor.

Weeds such as *Xanthium strumarium* L., *Abutilon theophrasti* Medik., *Solanum nigrum* L., *Datura stramonium* L., *Ambrosia artemisiifolia* L., *Cirsium arvense* (L.) Scop., *Sinapis arvensis* L. pose a substantial threat to sunflower crops as they compete for moisture, nutrients, and light, significantly diminishing sunflower performance. In some regions, the inefficacy of existing herbicides in controlling these weeds has neces-

sitated the breeding and selection of sunflower hybrids resistant to herbicides from the sulfonylurea and imidazolinone groups. The development of herbicides resistant to tribenuron methyl (a sulfonylurea herbicide) has enabled effective control of key broadleaf and grassy weeds in sunflower fields, including the parasitic weed broomrape (*Orobanche cumana*) (Vrbnicanin S et al, 2017; Clarke CR et al, 2019).

The advent of herbicide-tolerant crops has been made possible by a new understanding of herbicide mechanisms at the molecular level and the development of innovative biotechnology methods (Yalcin K et al, 2018). In North America, wild sunflower (*Helianthus annuus* L.) populations have become weeds in corn and soybean fields, necessitating extensive herbicide application. Over time, sunflower plants resistant to herbicides from the imidazolinone (IMI) and sulfonylurea (SU) groups have emerged (Seiler GJ et al, 2017; Hristova-Cherbadzhi M, 2022; White AD et al, 2002; Godar AS et al, 2013). This discovery has led to intensive efforts to create sunflower hybrids that are resistant to sulfonylurea herbicides.

At present, two distinct sources of resistance to sulfonylurea herbicides have been identified. In the first instance, resistance to tribenuron methyl was transferred from wild populations of *Helianthus annuus* L. to cultivated annual sunflowers (*H. annuus* L.) through traditional breeding methods. This effort resulted in the creation of two resistant lines, namely SURES-1 and SURES-2 (Bozic D et al, 2012; Kaya Y et al, 2012). The second source of resistance, denoted as SU7, was obtained through chemical mutagenesis using Ethyl Methanesulfonate (EMS) by the Pioneer company. Pioneer presented data demonstrating that sunflower plants acquired resistance to sulfonylurea herbicides via EMS-induced mutations, akin to those observed in wild sunflower populations. Following the development of these resistant genotypes, widespread global investigations into the inheritance of this trait were initiated (Canadian Food Inspection Agency, 2008).

In practice, nearly all forms of herbicide tolerance exhibit either complete or incomplete dominance. The genotypes SURES-1 and SURES-2 are homozygous for the gene conferring resistance to tribenuron methyl. Crosses involving these lines produced a first generation ( $F_1$ ) of hybrids displaying complete resistance to tribenuron methyl, thus indicating complete dominance. To elucidate the inheritance pattern of sulfonylurea herbicide resistance in source SU7, a comprehensive analysis was conducted over five generations. The

study findings revealed the presence of a single dominant gene that segregated according to Mendel's law, as evidenced by its phenotypic expression in the second generation (Jocic S et al, 2011; Sala C et al, 2012).

Sulfonylurea herbicides function as potent and specific inhibitors of the enzyme acetohydroxyacid synthase (AHAS), also known as acetolactate synthase (ALS) (Jocic S et al, 2011; Kolkman JM et al, 2004). These herbicides offer several advantages, including their effectiveness at low application rates, a broad spectrum of weed control, and a relative lack of toxicity to animals (Bozic D et al, 2015). Once applied to the leaves and roots of target weeds, these substances rapidly translocate throughout the entire plant, ultimately leading to its demise. Herbicides containing the active ingredient tribenuron methyl are particularly known for their rapid action and are recommended for post-germination treatments (Santos G et al, 2012; Jursik M et al, 2017).

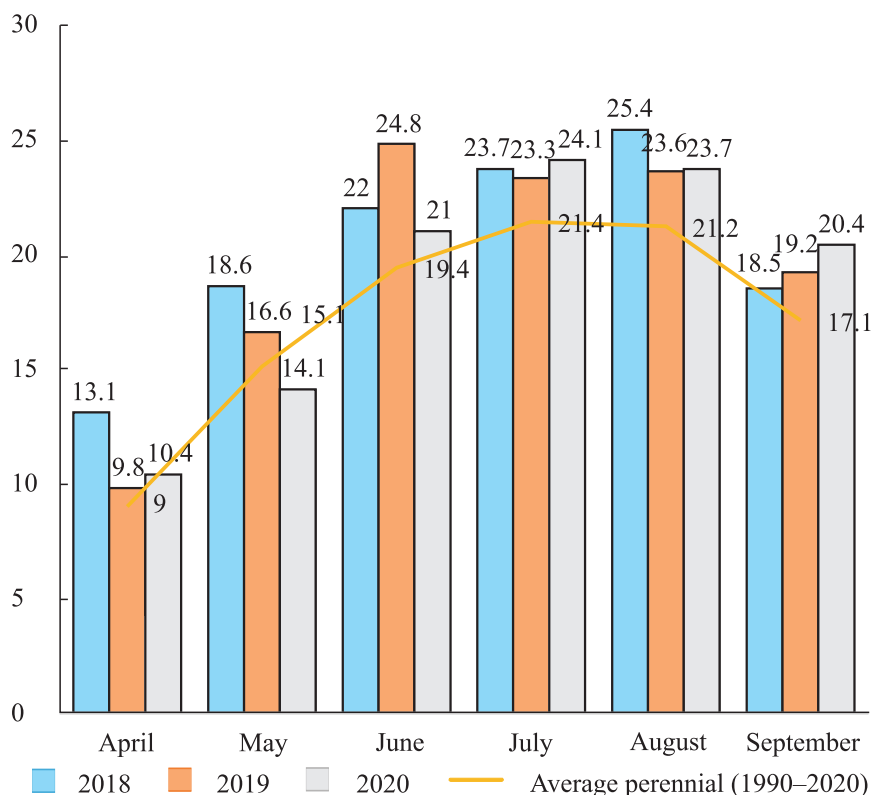
The primary aim of this study is to investigate the inheritance patterns of sulfonylurea herbicide resistance in sunflowers through hybridization analysis under conditions of insufficient humidification in the southern Steppe of Ukraine.

## MATERIALS AND METHODS

The research was conducted in the fields of the Selection and Genetics Institute – National Center of Seed and Cultivar Investigation (SGI-NCSCI) within the scientifically established crop rotation plan for the years 2018 to 2020. The study site was located in the department of selection and seed study of cross-pollinating crops in the village of Dachna, Biliiaiiv district, Odesa region, Ukraine.

The southern Steppe of Ukraine, where the study was conducted, experiences a notable continental climate with dry summers. According to the long-term data collected by the Odesa agrometeorological station, the average annual air temperature in this region is approximately +9.6 °C, with peak temperatures reaching around +30 °C. The accumulated sum of temperatures above 10 °C ranges between 3,200 and 3,400 degree-days. Annually, the region receives a limited amount of precipitation, typically averaging about 350–390 mm. The relative air humidity for the year averages around 62 %, with a hydrothermal coefficient of 0.7–0.8.

Summer temperatures in the region are notably high. The long-term average daily temperature for June is +19.6 °C, for July it is +22.5 °C, and for August, it is +21.0 °C. These high temperatures can result in soil



**Fig. 1.** The average monthly air temperature during the vegetation period (April–September), °C (2018–2020)

surface temperatures reaching as high as 50 °C. Precipitation during the summer months is infrequent and mainly occurs as sporadic rain showers. Due to the elevated air temperatures, precipitation events with less than 6 mm of rainfall are not effectively utilized by plants.

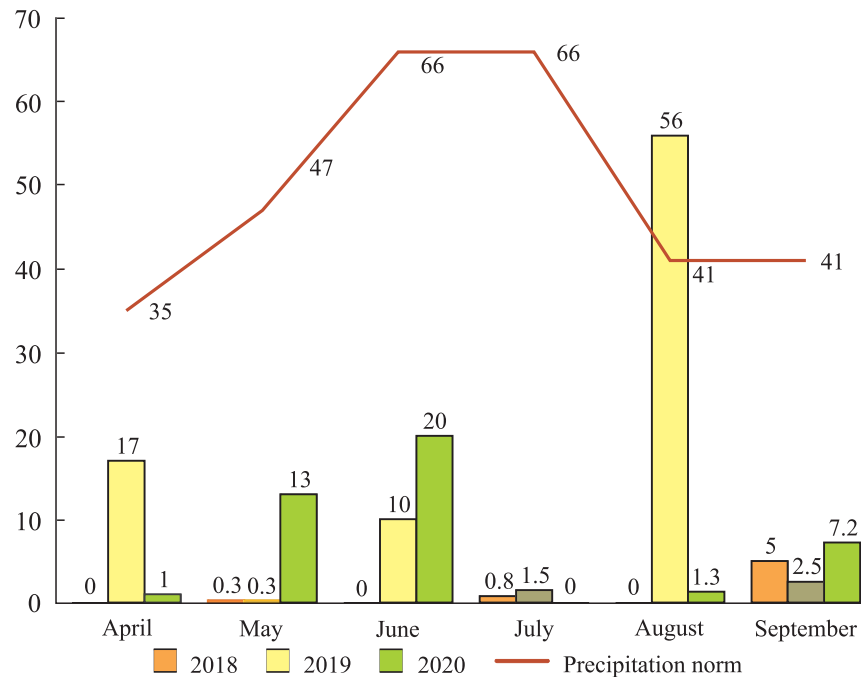
Throughout the years of our investigations, there was no significant deviation in air temperatures, but they consistently remained above the long-term annual average temperature (**Fig. 1**).

The amount of precipitation during the vegetation period from 2018 to 2020 deviated from the typical conditions observed in the southern Steppe zone (**Fig. 2**). Over these three years of investigation, we encountered unusually hot summers characterized by a significant moisture deficit.

The Steppe region of Ukraine presents a diverse range of climatic conditions, transitioning from relatively humid in the western part of the Forest-Steppe to exceptionally dry in the southern Steppe. In terms of the water balance coefficient, two distinct humidification zones are identified within Ukraine: non-resistant (characterized by coefficients close to one) and insufficient (where the coefficient falls below one). Even in the primary irrigated areas of Ukraine,

encompassing regions such as Odesa, Mykolayiv, and Kherson, the water balance coefficient falls in the range of 0.50 to 0.68, categorizing them as regions with insufficient humidification (Todorova LV et al, 2019).

Four sunflower hybrids, namely OS 2017 V × OS 1099 V, SURES-1 × Od 1002 B, SURES-1 × Od 1318 V, and Od 1318 V × OS 1295 V, served as the initial breeding materials (*Helianthus annuus* L.) for generating F<sub>1</sub> hybrid populations. Additionally, three hybrid populations, F<sub>2</sub> OS 2017 V × OS 1099 V, F<sub>2</sub> SURES-1 × Od 1002 B, and F<sub>2</sub> SURES-1 × Od 1318 V, were included in the study. These hybrids were obtained through the cross-breeding of paternal self-pollinated lines classified as either resistant (SURES-1, OS 2017 V, and OS 1099 V) or non-resistant (Od 1002 B, Od 1318 V, and OS 1295 V) to the sulfonylurea herbicide Granstar Pro 75 % w.g. (a.s. tribenuron methyl, 750 g/kg) (Solodenko AY a et al, 2018; Solodenko AE et al, 2018). It is noteworthy that lines SURES-1 and Od 1002 B exhibit pollen sterility, while the remaining lines (OS 2017 V, OS 1099 V, OS 1318 V, OS 1295 V) restore pollen fertility (Ilchenko et al, 2020). F<sub>2</sub> plants resulting from crosses between SURES-1 × Od 1002 B, OS 2017 V × OS 1099 V, and SURES-1 × OS 1318 V were analyzed separately.



**Fig. 2.** The sum of precipitation during the vegetation period (April–September), mm (2018–2020)

In 2018, initial crossbreeding of self-pollinated lines was conducted, and selected pairs were isolated for crossing before the onset of flowering, using pair isolators. Prior to isolation, external leaves of the cover and leaves near its base in the baskets were removed. Anthers in maternal lines, namely OS 2017 V, SURES-1, and OS 1318 V, were carefully removed using forceps that had been sanitized with an alcohol solution before each use. Hybridization was carried out from 6 a.m. to 9 a.m. throughout the entire flowering period.  $F_1$  and  $F_2$  hybrids were obtained in 2019 and 2020, respectively.

The herbicide Granstar Pro 75 % w.g. (a.s. tribenuron methyl) manufactured by the DuPont company, was utilized in this study. This herbicide is recognized as a systemic agent designed for post-germination control of dicotyledonous weeds. It exhibits a broad spectrum of efficacy on weeds, including those that are resistant to hormonal herbicides like 2,4-D. The application of this herbicide leads to the cessation of further weed growth. Visible symptoms of damage begin to appear within 5 to 8 days after application, and complete plant death is typically observed within 10 to 25 days. In cooler and drier climates, the herbicide's effectiveness may be somewhat reduced, whereas increased climatic indices enhance its efficiency. The recommended growth stage for applying the herbicide to sunflower plants is when they have reached 3 to 6 pairs of true leaves. A notable advantage of this herbicide is that its efficacy remains

unaffected by precipitation occurring up to three hours after field treatment.

Hybrid populations were subjected to herbicide treatment when they reached the stage of three true leaves. The herbicide Granstar Pro 75 % w.g. was applied at a dosage of 25 g/ha using a Spray MASTER-2000 sprayer. Resistance to the herbicide was assessed on the 14<sup>th</sup> day after treatment, with the number of plants treated with tribenuron methyl being categorized as either resistant or non-resistant. Non-resistant plants displayed phenological signs such as growth termination, tissue necrosis, and damage to the apical point.

In evaluating hybrid populations of the second generation ( $F_2$ ), a chi-square test for differences ( $\chi^2$ ) was employed. The values of  $\chi^2$  correspondence for the  $F_2$  population were consistent with a 3:1 ratio. The difference between observed and expected frequencies was statistically insignificant ( $\chi^2_{act} < \chi^2_{0.05}$ ), leading to the acceptance of the null hypothesis ( $H_0$ ) (Dosphehov BA, 1985).

## RESULTS

The outcomes of treating  $F_1$  sunflower plants with the herbicide resulted in the identification of three specific crossing combinations: OS 2017 V  $\times$  OS 1099 V, SURES-1  $\times$  Od 1002 B, and SURES-1  $\times$  Od 1318 V, all of which exhibited complete resistance in individual plants. Notably, all hybrid plants in the combination Od 1318 V  $\times$  OS 1295 V perished upon contact with the herbicide (**Table 1**).

**Table 1.** Inheritance of sulfonylurea herbicide resistance trait in sunflower hybrids (*Helianthus annuus* L.) F<sub>1</sub>

Hybrids F <sub>1</sub>	Resistance	The number of plants, it.		
		Total number of plants, treated with herbicide, it.	Resistant, it.	Non-resistant, it.
OS 2017 V × OS 1099 V	R × R	32	32	0
SURES-1 × Od 1002 B	R × N	30	30	0
SURES-1 × Od 1318 V	R × N	44	44	0
Od 1318 V × OS 1295 V	N × N	38	0	38

Note. \*R – resistance, N – non-resistance of self-pollinated lines to the effect of a sulfonylurea herbicide.



**Fig. 3.** Sunflower plant responses to herbicide Granstar Pro 75% w.g. *a* – end of the first week post-treatment; *b* – end of the second week, start of the third week post-treatment; *c* and *d* – genotype SURES 1, resistant to tribenuron methyl, on day 14 post-treatment

Upon herbicide exposure, susceptible sunflower plants initially displayed a decline in growth, often characterized by damage to the apical point. This initial effect was followed by yellowing, deformity, and necrosis of vegetative plant organs, ultimately leading to the complete demise of the sunflower plants (**Fig. 3**).

Subsequent to the acquisition of F<sub>2</sub> seeds, first-generation hybrids were induced to self-pollinate. The plants of the second generation were then subjected to herbicide treatment at the stage of three true leaves, and the results are detailed in **Table 2**.

In the case of the combination OS 2017 V × OS 1099 V, complete resistance to the herbicide Granstar Pro

75 % w.g. was observed in individual plants. This resistance was consistently demonstrated by plants from all five baskets. This observation suggests the presence of a dominant allele of the gene *AHAS1* in the homozygous state within the genotypes of the paternal lines.

Within the combination SURES-1 × Od 1002 B, the number of homozygous and heterozygous plants unaffected by the herbicide in each of the three baskets was 31, 40, and 31 individual plants, while 6, 9, and 5 were non-resistant. This distribution aligns with a 3:1 ratio ( $\chi^2_{3:1} = 1.52; 1.15, \text{ and } 2.37; \text{ at } \chi^2_{\text{exp.}} = 3.84$ ).

In the combination SURES-1 × Od 1318 V, the number of resistant plants, obtained from F<sub>2</sub> seeds in five

**Table 2.** Segregation analysis of F<sub>2</sub> hybrid populations in sunflower (*Helianthus annuus* L.)  $\chi^2_{3;1} < 3.84$  for df = 1

Hybrids F <sub>2</sub>	Total number of plants, treated with herbicide, it.	Resistant plants, it.	Non-resistant plants, it.	$\chi^2_{3;1}$
OS 2017 V × OS 1099 V/1	59	59	0	19.67
OS 2017 V × OS 1099 V/2	48	48	0	16.00
OS 2017 V × OS 1099 V/3	65	65	0	21.67
OS 2017 V × OS 1099 V/4	53	53	0	17.67
OS 2017 V × OS 1099 V/5	49	49	0	16.33
SURES-1 × Od 1002 B/1	37	31	6	1.52
SURES-1 × Od 1002 B/2	49	40	9	1.15
SURES-1 × Od 1002 B/3	36	31	5	2.37
SURES-1 × OS 1318 V/1	67	56	11	2.63
SURES-1 × OS 1318 V/2	54	46	8	2.99
SURES-1 × OS 1318 V/3	49	41	8	1.97
SURES-1 × OS 1318 V/5	37	28	9	0.01
SURES-1 × OS 1318 V/6	38	32	6	1.72

Note.  $\chi^2_{3;1} = 3.84$  for df = 1.

baskets, was 56, 46, 41, 28, and 32, whereas the non-resistant plants numbered 11, 8, 8, 9, and 6, respectively. The observed distribution of shares aligns with Mendel’s second law for differences between parents concerning the alleles of a single gene ( $\chi^2_{3;1} = 2.63; 2.99; 1.97; 0.01; 1.72$ , at  $\chi^2_{exp.} = 3.84$ ).

The consistent 3:1 segregation pattern (resistant: non-resistant) in the F<sub>2</sub> generation of the two crossing combinations (SURES-1 × Od 1002 B and SURES-1 × Od 1318 V) indicates that the trait of resistance to tribenuron methyl is under the control of a single gene. In this monogenic control, the dominant allele of the gene imparts resistance to the herbicide, while the recessive allele renders the plant sensitive to the herbicide’s effects.

### DISCUSSION

Determining the genetic basis of herbicide resistance represents a complex area of investigation. Given that donor populations exhibit a multitude of traits, which are characteristic of wild *Helianthus annuus* L. populations, investigating the genetics of tolerance necessitates preliminary studies on self-pollinated lines that are resistant to tribenuron methyl.

Self-pollinated lines, created through the crossing of SURES-1 with lines Na-26, VL-A-8, and Kha-48, displayed tolerance to a double dose of tribenuron methyl. An examination of the mutation responsible for endowing sunflowers with resistance to herbicides from the sulfonylurea and imidazolinone groups revealed that populations of SURES-1 and SURES-2

contained the Pro197 mutation. This mutation is one of the most common mutations found in cultivated plants resistant to acetolactate synthase (ALS)-inhibiting herbicides (Kolkman et al, 2004). Further studies, aimed at developing hybrids resistant to tribenuron methyl, demonstrated that progenies of the initial populations resulting from crosses with SURES-1 and SURES-2 exhibited complete tolerance to tribenuron methyl, indicating that these populations were entirely homozygous for this trait. In the F<sub>1</sub> generations, complete resistance was observed, with slight chlorosis, yet no growth delay compared to the treated control variant, illustrating complete dominance (Sinisa J et al, 2011).

S. O. Kirienko observed a monogenic inheritance pattern of resistance in both the first (F<sub>1</sub>) and second (F<sub>2</sub>) hybrid generations, characterized by complete dominance (Kirienko S, 2015). This monogenic inheritance pattern represents a promising approach for developing resistant hybrids because, to create it, obtaining a single resistant paternal component suffices, significantly streamlining the breeding process. When the phenotypic expression of a particular trait is influenced by a complex genetic system, such a sample should not be regarded as a universal donor of that trait, as it may not guarantee the desired result when combined with other paternal components (Lebedenko Ie, 2019).

In our study, the F<sub>1</sub> hybrids OS 2017 V × OS 1099 V, SURES-1 × Od 1002 B, and SURES-1 × Od 1318 V displayed complete resistance to the herbicide Granstar Pro 75 % w.g. and exhibited two distinct phenotypic classes: resistant and non-resistant. Importantly, there

was a conspicuous absence of an intermediate phenotypic class characterized by symptoms such as yellowing (chlorosis), deformity of plant organs, and growth delay, which may suggest the presence of modifying genes or incomplete dominance of the trait. Consequently, the inheritance pattern of the resistance trait to sulfonylurea herbicides in the first-generation hybrids, when exposed to the standard herbicide dose (25 g/ha), is indicative of complete dominance.

The segregation patterns observed in the hybrid populations  $F_2$ , which resulted from self-pollination of  $F_1$  plants, further confirmed the monogenic inheritance pattern, as evidenced by the consistent 3:1 ratio (resistant: non-resistant).

### CONCLUSIONS

The investigation into the inheritance of resistance to sulfonylurea herbicides, conducted within the challenging climatic conditions of the southern Steppe of Ukraine, revealed significant insights into the genetic basis of resistance in sunflower plants. Notably, in the  $F_1$  generation, all hybrid combinations exhibited complete resistance to the herbicide Granstar Pro 75% w.g. when one paternal component possessed resistance to the herbicide.

In the second generation, as observed in the combination OS 2017 V  $\times$  OS 1099 V, there was no segregation of resistant and non-resistant individuals, primarily because both paternal components in this hybrid were inherently resistant to the herbicide's effects. This emphasizes the significance of selecting resistant paternal components when aiming to create herbicide-resistant sunflower hybrids.

Furthermore, the outcomes of splitting in the  $F_2$  populations, specifically in the cases of SURES-1  $\times$  Od 1002 B and SURES-1  $\times$  Od 1318 V, conclusively indicated that the resistance to tribenuron methyl in the self-pollinated lines employed in this study was under the control of a dominant gene allele. This genetic insight paves the way for more effective breeding strategies, offering a simplified approach to develop sunflower hybrids with increased herbicide resistance.

**Adherence to ethical principles.** No experiments, described in this article, involved the use of animals.

**Conflict of interests.** The authors declare the absence of any conflicts of interests.

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tions for the breeding of sunflower hybrids with complex resistance to diseases and broomrape, adapted to conditions of insufficient and unstable humidification of the southern Steppe of Ukraine" which is a part of ASR 16 "Sunflower: the basics of production process management" ("Sunflower").

#### Успадкування стійкості соняшнику до трибенурон-метилу в умовах недостатнього зволоження Південного Степу України

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**Мета.** Дослідження успадкування ознаки «стійкість до гербіцидів групи сульфонілсечовин» у соняшнику в умовах недостатнього зволоження Південного Степу України. **Методи.** Ізолювання, кастрація, гібридизація, обприскування гібридів  $F_1$  та рослин  $F_2$  гербіцидом Грансар Про 75 % в.г. (д.р. трибенурон-метил), оцінка стійкості до гербіциду, статистична обробка отриманих результатів. **Результати.** Для дослідження ознаки успадкування «стійкість до гербіцидів групи сульфонілсечовин» були використанні стійкі (SURES-1, ОС 1099 В, ОС 2017 В) та нестійкі (Од 1002 Б, Од 1318 В, ОС 1295 В) генотипи соняшнику. В результаті схрещувань отримали чотири гібридні комбінації  $F_1$ : ОС 2017 В  $\times$  ОС 1099 В, SURES-1  $\times$  Од 1002 Б, SURES-1  $\times$  Од 1318 В та Од 1318 В  $\times$  ОС 1295 В. Після обробки рослин  $F_1$  гербіцидом Грансар Про 75 % в.г. виділили три комбінації (ОС 2017 В  $\times$  ОС 1099 В, SURES-1  $\times$  Од 1002 Б, SURES-1  $\times$  Од 1318 В), які показали повну стійкість до препарату. У другому поколінні, після обробки рослин гербіцидом, у гібридних комбінації SURES-1  $\times$  Од 1002 Б, SURES-1  $\times$  Од 1318 В спостерігали розщеплення на стійкі та нестійкі. Рослини комбінації ОС 2017 В  $\times$  ОС 1099 В показали повну стійкість до дії гербіциду. **Висновок.** Дослідження, які проведені в умовах Південного Степу України по успадкуванню ознаки «стійкість до гербіцидів групи сульфонілсечовин», показали повну стійкість рослин соняшнику у трьох гібридних комбінації  $F_1$  та  $F_2$ . У рослин  $F_2$  комбінації ОС 2017 В  $\times$  ОС 1099 В не спостерігали розщеплення. За результатами розщеплення популяції другого покоління (SURES-1  $\times$  Од 1002 Б,

SURES-1 × Од 1318 В) встановили, що стійкість до трибенурон-метилу, обумовлена дією домінантного алеля гена.

**Ключові слова:** соняшник, стійкість до гербіцидів, сульфонілсечовина, трибенурон-метил, успадкування, ген *AHAS*.

## REFERENCES

- Bozic D, Pavlovic D, Bregola V, Di Loreto A, Vrbnicanin S (2015) Gene Flow from Herbicide-Resistant Sunflower Hybrids to Weedy Sunflower. *J Plant Dis Protect* 122: 183–188. <https://doi.org/10.1007/BF03356548>
- Bozic D, Saric M, Malidza G, Ritz C, Vrbnicanin S (2012) Resistance of sunflower hybrids to imazamox and tribenuron-methyl. *Crop Protection*. 39:1–10. <https://doi.org/10.1016/j.cropro.2012.04.009>
- Canadian Food Inspection Agency (2008) Determination of the Safety of Pioneer Hi-Bred Production Ltd.'s Sulfonylurea-Tolerant ExpressSun™ Sunflower (*Helianthus annuus* L.) SU7. 2008 [online resource]. Access mode URL: <http://www.inspection.gc.ca/english/plaveg/bio/dd/dd0869e.shtml>
- Clarke CR, Timko MP, Yoder JI, Axtell MJ, Westwood JH (2019) Molecular dialog between parasitic plants and their hosts. *Ann Rev Phytopathol* 57:279–299. <https://doi.org/10.1146/annurev-phyto-082718-100043>
- Dospheov BA (1985) Field experience methodology (with the basics of statistical processing of research results). 5:199–207. (in Russian)
- Godar AS, Stahlman PW, Dille JA (2013) Efficacy of tribenuron alone and following preemergence herbicides in tribenuron-resistant sunflower. *Online. Crop Managem Res* 12(1). <https://doi.org/10.1094/CM-2013-0621-01-RS>
- Hristova-Cherbadzhi M (2022). Pesticides and Sunflower Breeding. In *Pesticides-Updates on Toxicity, Efficacy and Risk Assessment*. IntechOpen. <https://doi.org/10.5772/intechopen.104478>
- Ilchenko AS, Varenyk BF, Lamari NP (2020) Formation of a characteristic collection of sunflower (*Helianthus annuus* L.) genotypes resistant to sulfonylurea herbicides. *Agrarian innovations*. 4:108–114. <https://doi.org/10.32848/agr.ar.innov.2020.4.16>
- Jocic S, Malidza G, Cvejic S, Hladni N, Miklic V, Skoric D (2011) Development of sunflower hybrids tolerant to tribenuron methyl. *Genetika* 43(1):175–182. <https://doi.org/10.2298/GENSR1101175J>
- Jursik M, Fendrychova V, Kolarova M, Andr J, Soukup J (2017) Optimising Clearfield and ExpressSun sunflower technologies for Central European conditions. *Plant Protect Sci* 53:265–272. <https://doi.org/10.17221/2/2017-PPS>
- Kaya Y, Jocic S, Miladinovic D (2012) Sunflower. *Technological Innovations in Major World Oil Crops* 1:85–129. [https://doi.org/10.1007/978-1-4614-0356-2\\_4](https://doi.org/10.1007/978-1-4614-0356-2_4)
- Kaya Y, Sahin S, Beşer N (2018) Determining of yield performances of some IMI resistant sunflower hybrids in Trakya region, Turkey. *Eurasia Proc Sci Technol Engineer Mathemat* 3:126–132
- Kolkman JM, Slabaugh MB, Bruniard JM, Berry S, Bushman BS, Olungu Ch, Maes N, Abratti G, Zambelli A, Miller JF, Leon A, Knapp SJ (2004) Acetohydroxyacid synthase mutations conferring resistance to imidazolinone or sulfonylurea herbicides in sunflower. *Theor Appl Gen* 109:1147–1159. <https://doi.org/10.1007/s00122-004-1716-7>
- Kirienco S (2015) Creation of fertility restorers of sunflower resistant to the herbicide express 75 w.g. Ukrainian Black Sea region agrarian science. 3(86):153–158 (in Ukrainian).
- Lebedenko Ie O (2019) Breeding of Starting Material for Creation of Sulfonylurea Herbicide-Resistant Sunflower Hybrids. Dissertation for obtaining the degree in Agricultural Sciences (Doctor of Philosophy). Kherson (in Ukrainian)
- Sala C, Bulos M, Altieri E, Ramos M (2012) Genetics and breeding of herbicide tolerance in sunflower. *Helia*. 35(57):57–70. <https://doi.org/10.2298/hel1257057s>
- Santos G, Francischini AC, Constantin J, Oliveira RS, Ghiglione H, Velho GF, Oliveira Neto AM (2012) Use of the new Clearfield system in sunflower culture to control dicotyledonous weeds. *Planta Daninha* 30:359–365. <https://doi.org/10.1590/S0100-83582012000200015>
- Seiler GJ, Qi LL, Marek LF (2017) Utilization of sunflower crop wild relatives for cultivated sunflower improvement. *Crop Sci* 57(3):1083–1101. <https://doi.org/10.2135/cropsci2016.10.0856>
- Solodenko AYe, Fayt VI (2018) Usage of DNA markers for screening and identification of sunflower genotypes of hybrid origin on *AHAS1* gene. *Oil Crops*. 1(173):3–9. <https://doi.org/10.25230/2412-608X-201-1-173-3-9> (in Ukrainian)
- Solodenko AYe, Ilchenko AS, Varenyk BF (2018) Effectiveness of microsatellite marker pahas 16–17 for introgression of herbicide resistance gene *ahas1* into sunflower breeding material. *Visnyk of the Kharkiv National Agrarian University named after V.V. Dokuchaev*. 44(2):94–99 (in Ukrainian)
- Todorova LV, Malyuk TV, Fedosova AO (2019) Analysis of the peculiarities of changes in hydrothermal conditions of the southern region of Ukraine. 178–180 (in Ukrainian)
- Vrbnicanin S, Bozic D, Pavlovic D (2017) Gene flow from herbicide-resistant crops to wild relatives. In: Pacanoski Z (ed) *Herbicide resistance in weeds and crops*. IntechOpen. 37–63. <https://doi.org/10.5772/67645>
- White AD, Owen MD, Hartzler RG, Cardina J (2002) Common sunflower resistance to acetolactate-inhibiting herbicides. *Weed Sci* 50(4):432–437. [https://doi.org/10.1614/0043-1745\(2002\)050\[0432:CSRTAS\]2.0.CO;2](https://doi.org/10.1614/0043-1745(2002)050[0432:CSRTAS]2.0.CO;2)