Effect of Abiotic Factors on Herbicide Tolerance in *Solanum Nigrum* Populations

Abiotikus tényezők hatása a fekete csucsor (Solanum nigrum) herbicid toleranciájára

Rita Ofosu[1]*, Gabriella Kazinczi[1] and János Taller[2]

[1]*Hungarian University of Agriculture and Life Sciences, Institute of Plant Protection, Department of Plant Protection; pacseszakne.kazinczi.gabriella@uni-mate.hu*

[2]*Hungarian University of Agriculture and Life Sciences, Institute of Genetics and Biotechnology, Department of Microbiology and Applied Biotechnology; taller.janos@uni-mate.hu*

**Correspondence: rita.of13@gmail.com*

Abstract: Abiotic factors such as light, temperature, relative humidity, soil moisture and carbon dioxide have an effect on herbicide efficacy and performance. As weeds continue to evolve with changes in climate, it is important to understand the impact on herbicide effectiveness in management strategies. In this paper, we describe changes in the sensitivity of black nightshade (*Solanum nigrum*) population to glyphosate under different growing conditions and demonstrate that resistance mechanism may be climate dependent. Young *Solanum nigrum* plants were treated with normal and double dose rates of glyphosate. Observations were recorded 5, 14, 21 and 28 days consecutively after treatment with glyphosate. Some of the *Solanum nigrum* populations exhibited some level of tolerance to glyphosate in the first round of the experiment for both normal and double dose under ambient conditions. However, a repeat experiment using the same samples and treatment in a controlled environment (growing chamber) where growing conditions was set did not yield the same observations made under ambient conditions. Further investigations and experiments are recommended and may provide more explanation to the differences in results obtained for initial tolerance in *Solanum nigrum* samples which could be attributed to the differences in growing conditions.

***Keywords**: Solanum nigrum; abiotic factors; herbicide resistance; climate; glyphosate*

Összefoglalás: Az abiotikus tényezők - mint a fény, a hőmérséklet, a talajnedvesség, légköri széndioxid koncentráció - jelentősen befolyásolják a gyomirtó szerek hatékonyságát. Mivel a gyomállomány összetételére az éghajlati tényezők jelentős hatást gyakorolnak, fontos megérteni a herbicidek hatékonyságára gyakorolt hatást is, a sikeres kezelési stratégiák kidolgozása érdekében. Ebben a munkában a fekete csucsor (*Solanum nigrum*) glifozáttal szembeni reakcióját vizsgáltuk annak érdekében, hogy bizonyítsuk, a herbicidekkel szembeni reakciót a klimatikus tényezők is befolyásolhatják. Ezért fiatal fekete csucsor növények glifozáttal szembeni reakcióját vizsgáltuk dózis-hatás kísérletekben szabadföldön, és kontrollált körülmények között klímakamrában. Az eredmények eltérőek voltak, ami azt valószínűsíti, hogy az abiotikus tényezők jelentősen hatnak a vizsgált gyomfaj/biotípus herbicid érzékenységére, de ennek egzakt bizonyítására további vizsgálatok szükségesek.

***Kulcsszavak**: Solanum nigrum; abiotikus faktorok; herbicid ellenálló képesség; klíma; glifozát*

1. Introduction

Climate is a critical factor in food production and climate change remains one of the defining global issues in recent times. However, irrespective of how the climate patterns change, weeds will continue to be present due to their ability to adapt to various environmental conditions (Bajwa et al., 2021; Mahaut et al., 2020). Agricultural weeds are of particular concern since they have severe impact on global food security and as such, it is important to highlight the effects of abiotic conditions on weed management (Matzrafi et al., 2016). Weeds are highly adaptive and able to withstand several stressors related to climate change such as increase in temperatures, increased carbon dioxide (CO2) levels, drought and waterlogging (Hicks et al., 2018). The effect of weeds on crop production can be very severe if not properly managed (Chen et al., 2020; Kathiresan and Gualbert, 2016). Herbicides have been used in many management strategies across the globe, this is because herbicides provide rapid action, efficient and cost effective mechanism for controlling weeds. However, the increasing numbers of recorded cases of herbicide resistant weeds worldwide is quite alarming and calls for more research focused on resistance development (Travlos et al., 2020). Climate conditions such as temperature, atmospheric CO2 and precipitation are likely to affect weed biology. These factors affect the penetration of herbicide into the plant and indirectly influence the movement of herbicide within the plant. (Ziska et al., 2019). Herbicide performance can also be affected by abiotic, physiological, and biological factors thus, limiting weed control effectiveness (Torra et al., 2021). Study by Ge et al. (2011) reported resistance of horseweed (Conyza canadensis) to glyphosate in response to temperature. The particular increase in herbicide resistance cases especially metabolism based non-target site (NTS) resistance and multiple resistance calls for in-depth study into environmental effects on herbicide performance for improved weed control. Research has shown that a significant proportion of reported cases of NTS herbicide resistance is related to acetyl-CoA carboxylase (ACCase) inhibitors used to control grass weeds in cereal crops and to 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) inhibitor, glyphosate, most intensively used herbicide to control weeds globally (Délye 2013; Matzrafi et al., 2016).

In Hungary, herbicides are used in many weed management strategies and there have been several reported cases of herbicide resistant weeds. Common ragweed (*Ambrosia artemisiifolia*), johnsongrass (*Sorghum halapense*), Italian cocklebur (*Xanthium italicum*) and green amaranth (*Amaranthus powellii*) have been found resistant to a number of acetolactate synthase (ALS) inhibitors in Hungary (Szabó et al., 2018; Kazinczi-Torma, 2016). Glyphosate-resistant *Conyza canadensis* have been reported (Kutasy et al., 2021; Heap, 2023). Although there are currently no recorded cases of herbicide resistant *S. nigrum* in Hungary, the weed is common occuring in areas with high nitrogenous soils and farmlands in Hungary where herbicides are used to management strategies (Kazinczi et al., 2002). Since forecast for the future continue to predict changes in climate patterns globally, the phenomenon of metabolic resistance to herbicides will dramatically increase in agricultural systems. This highlights the need for more research in the area of herbicide resistance development. In this paper, changes in the sensitivity of *Solanum nigrum* population to glyphosate under different growing conditions is studied and described.

2. Materials and Methods

Matured seeds of *Solanum nigrum* were collected from vineyards in Balatonboglár and Cserszegtomaj where the main method of weed control was with the use of herbicides. Seed samples were taken from individual plants suspected to be resistant after treatments with

glyphosate. Seeds were also collected from wastelands at Kaposvár. The collected seeds were cleaned and cold stratified to break dormancy. After stratification, the seeds were sown in three different trays and allowed to grow under ambient conditions. At 3-4 leaf stage, dose-response experiment was conducted and observations recorded. In the subsequent experiment, a dose-response experiment was performed under controlled conditions where the planted seeds were allowed to grow in a controlled environment with day temperature of 28°C and night temperature 20°C. For the experiment, treatments applied were, control (no herbicide), normal dose (1440 g glyphosate/ha in 250 l/ha of water) and double dose (2880 g glyphosate/ha in 250 l/ha of water). Each sample had four (4) replications per treatment as shown in Table 1. Observations were taken 5, 14, 21 and 28 days after treatment (DAT) with glyphosate.

Table 1: Experiment layout for glyphosate dose-response experiment with *Solanum nigrum*

	Tray 1	**Tray 2**	**Tray 3**
	Each sample replicated 4 times per tray		
Place of collection	No Treatment (Control)	Treatment with normal dosage	Treatment with double dosage
Balatonboglár	10 samples	10 samples	10 samples
Kaposvar	1 samples	1 samples	1 samples
Cserszegtomaj	9 samples	9 samples	9 samples
Total	80 samples	80 samples	80 samples

3. Results

It was observed during the experiment that the plants exhibited varied responses under ambient conditions and in the growth chamber. Initial symptoms of yellowing and wilting were observed 14 DAT and proceeded till death of plant by the 28 day for most of the plants. However, its was observed that some plants from seeds collected from Balatonboglár survived for both normal and double dose rates under ambient conditions with slight yellowing 28 DAT as observed in Figure 1. However, the same samples grown under controlled environment were susceptible to the effects of glyphosate after treatment with normal and double doses.

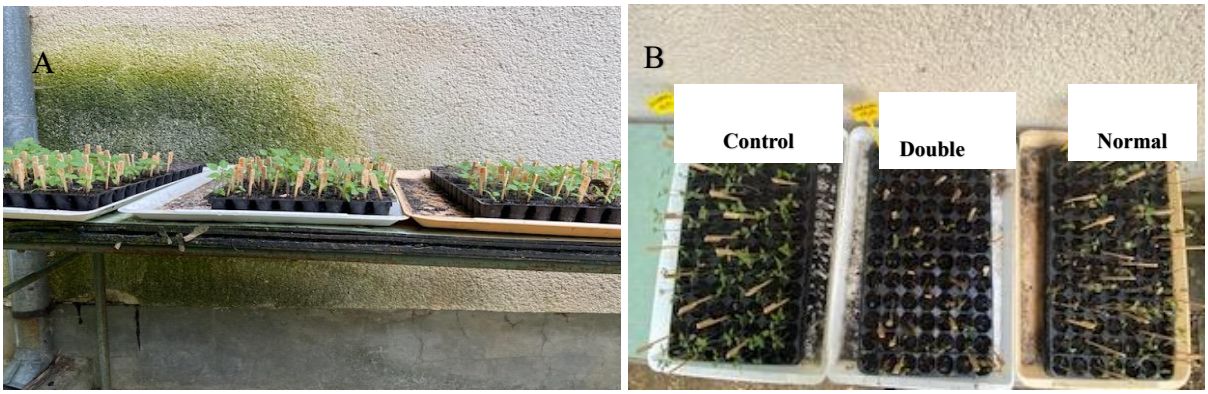

Figure 1. *(A) S. nigrum plants before treatment under ambient conditions. (B) S. nigrum plants 28 DAT. left: control with no treatment; middle: sprayed with double dose rate of glyphosate; right: sprayed with normal dose rate of glyphosate under ambient conditions. Photo: Rita Ofosu*

4. Discussion

The outcome of this experiment could be because of the differences in the environmental conditions under which the plants were grown. This result is comparable to previous work done by Vila-Aiub et al. (2013) where the efficacy of glyphosate on *S. halapense* was reported to have increased with high temperature. In an earlier work done by Kudsk (2017), abiotic factors such as temperature, light intensity and humidity can affect herbicide performance. The ambient temperature recorded for the period when the experiment was conducted was higher than the temperature in the controlled climate chamber with day temperature of 28°C and night temperature 20 °C which supports the finding that resistance mechanism is climate dependent, and that air temperature affects the growth of plants and the ability of the herbicide to produce targeted results. Also, previous studies have shown that increased temperature can affect levels of resistance to glyphosate (Ge et al., 2011). Thus the outcome of this experiment could suggest that the decrease in sensitivity of the *S. nigrum* population as observed under ambient growing conditions may be due to increased herbicide metabolism. Another reason could also be that the herbicide did not get contact with the weeds during the treatment application hence, the weeds survived. The time of application, precipitation, wind direction, humidity and temperature are important and should be considered when applying herbicides to achieve optimum results (Vila-Aiub et al., 2013). Further studies using the same weed populations are recommended and may provide in-depth explanation for the ineffectiveness of glyphosate on weed populations present at the sites of collection, the type of mechanisms used in decreasing the sensitivity of the population to glyphosate dose on the growing field and impact of environmental conditions on herbicide tolerance.

Acknowledgements

This study was carried out with support from the Hungarian Government, Tempus Public Foundation.

References

Bajwa, A., Matzraf, M., and Jugulam, M. 2021. Editorial: Biology and Management of Weeds and Invasive Plant Species Under Changing Climatic and Management Regimes. *Front. Agron*. 3 728144. https://doi.org/10.3389/fagro.2021.728144

Chen, J., Burns, E., Fleming, M. and Patterson, E. 2020. Impact of climate change on population dynamics and herbicide resistance in kochia (*Bassia scoparia* (L.) A. J. Scott). *Agronomy*. **10** 1700. https://doi.org/10.3390/agronomy10111700

Délye, C., Jasieniuk, M. and Le Corre, V. 2013 Deciphering the evolution of herbicide resistance in weeds. *Trends Genet*. **29** 649–658. https://doi.org/10.1016/j.tig.2013.06.001

Ge, X., d' Avignon, D. A., Ackerman, J. J., Duncan, B., Spaur, M. B. and Sammons, R. D. 2011. Glyphosate-resistant horseweed made sensitive to glyphosate: low-temperature suppression of glyphosate vacuolar sequestration revealed by 31P NMR. *Pest Management Science*. **67** (10), 1215–1221. https://doi.org/10.1002/ps.2169

Heap, I. 2023. International survey of herbicide resistant weeds. https://www.weedscience.org. Accessed on 14th November, 2023.

Hicks, H. L., Comont, D., Coutts, S. R., Crook, L., Hull, R., Norris, K., Neve, P., Childs, D. Z. and Freckleton, R. P. 2018. The factors driving evolved herbicide resistance at a national scale. *Nat. Ecol. Evol*. **2** (3) 529–536. https://doi.org/10.1038/s41559-018-0470-1

Kathiresan, R. and Gualbert, G. 2016. Impact of climate change on the invasive traits of weeds. *Weed Biology and Management*. **16** (2) 59–66. https://doi.org/10.1111/wbm.12096

Kazinczi, G., Horváth, J., Takács, A. P. and Pribék, D. 2002. Biological Decline of *Solanum nigrum* L. Due to Tobacco mosaic tobamovirus (TMV) Infection. II. Germination, Seed Transmission, Seed Viability and Seed Production. *Acta Phytopathologica et Entomologica Hungarica*. **37** (4) 329–333. https://doi.org/10.1556/APhyt.37.2002.4.3

Kazinczi, G. and Torma, M. 2016. Reactions of different *Sorghum halapense* (L.) Pers. Populations to Sulfonilurea Herbicides. *Hungarian Weed Research and Technology*. **17** (2) 35–47. (in Hungarian with an English summary).

Kudsk, P. 2017. Optimising Herbicide Performance. In: P. E. Hatcher - R. J. Froud-Williams (Eds.), Weed Research (pp. 149–179). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781119380702.ch6

Kutasy, B., Farkas, Z., Kolics, B., Decsi, K., Hegedűs, G., Kovács, J., Taller, J., Tóth, Z., Kálmán, N., Kazinczi, G. and Virág, E. 2021. Detection of target-site herbicide resistance in the common ragweed: nucleotide polymorphism genotyping by targeted amplicon sequencing. *Diversity*. **13** (3) Article 3. https://doi.org/10.3390/d13030118

Mahaut, L., Cheptou, P.-O., Fried, G., Munoz, F., Storkey, J. F., Vasseur, F., Violle, C. and Bretagnolle, F. 2020. Weeds: Against the Rules? *Trends in Plant Science*. https://doi.org/10.1016/j.tplants.2020.05.013

Matzrafi, M., Seiwert, B., Reemtsma, T., Rubin, B. and Peleg, Z. 2016. Climate change increases the risk of herbicide-resistant weeds due to enhanced detoxification. *Planta*. **244** 1217–1227. https://doi.org/10.1007/s00425-016-2577-4.

Szabó, R., Varga, Z., Grigely K., Károlyi, M., Pardi, J. and Szmola, D. 2018. Newly detected ALS resistant weeds from Hungarian soybean fields. *Hungarian Weed Research and Technology*. **19** (2) 37–45.

Torra, J., Osuna, M. D., Merotto, A. and Vila-Aiub, M. 2021. Editorial: Multiple herbicide-resistant weeds and non-target site resistance mechanisms: a global challenge for food production. *Front. Plant Sci*. (12) 763212. https://doi.org/10.3389/fpls.2021.763212

Travlos, I., de Prado, R., Chachalis, D. and Bilalis, D. J. 2020. Editorial: Herbicide resistance in weeds: early detection, mechanisms, dispersal, new insights and management issues. *Front. Ecol. Evol*. (8) 213. https://doi.org/10.3389/fevo.2020.00213

Vila-Aiub, M. M., Gundel, P. E., Yu, Q. and Powles, S. B. 2013. Glyphosate resistance in *Sorghum halepense* and *Lolium rigidum* is reduced at suboptimal growing temperatures: Glyphosate resistance and temperature. *Pest Management Science*. **69** (2) 228–232. https://doi.org/10.1002/ps.3464

Ziska, L., Blumenthal, D. and Franks, S. 2019. Understanding the nexus of rising CO2, climate change, and evolution in weed biology. *Invasive Plant Science and* Management. **12** (2) 79–88. https://doi.org/10.1017/inp.2019.12