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Evaluation of the use of leaf fertilizers and growth regulators in winter wheat: A review

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SUMMARY

Winter wheat is a leading cereal on a global scale, however, yields remain variable due to increasing weather extremes. This review synthesizes evidence (1971–2024) on the effects of foliar fertilizers and plant growth regulators/biostimulants on wheat growth, yield and quality. Across studies, appropriately timed foliar micronutrient applications (Fe, Mn, Cu, Zn, B, Mo) tend to enhance chlorophyll content, photosynthetic activity, and grain quality traits, while selected copper- and zinc-based products frequently increase grain yield and crude protein. Biostimulants—such as amino acids, humic/fulvic acids and seaweed extracts—generally improve stress tolerance (drought, cold) and may raise grain number and thousand-kernel weight. Plant growth regulators (e.g., lodging control agents) can reduce plant height, strengthen stems and improve stand stability, thereby contributing to yield security. Evidence magnitude varies with soil supply, cultivar, and phenophase-specific timing. We summarize practical windows of application, expected responses, and limitations, and highlight research gaps in standardizing doses and reporting effect sizes. Overall, foliar nutrition and growth regulation are promising tools to increase yield stability and quality under increasingly variable growing conditions.

Keywords: *winter wheat; foliar fertilizers; growth regulators; review*

INTRODUCTION

Based on the descriptions of Mándy (1971), the beginnings of winter wheat cultivation can be traced back to the area of the 'Fertile Crescent', where the remains of Einkorn wheat (*Triticum monococcum* L.) and Emmer wheat (*Triticum dicoccum* Schrank ex. Schübl.) have been found. The emergence of common wheat (*Triticum aestivum* L.) is the culmination of the history of wheat descent. The most probable mode of origin is that *Aegilops squarrosa* and Persian wheat (*Triticum carthlicum* Nevski) interbred and mutated to produce the hexaploid form. Given the global importance of winter wheat, yield stability is a major concern under climate change. Extreme weather events and abiotic stress factors increasingly limit production, necessitating strategies that complement traditional crop management. Foliar fertilizers and plant growth regulators, including biostimulants, have emerged as potential tools to stabilize yield and improve quality. The aim of this review is to critically evaluate the effects of foliar fertilizers and growth regulators on winter wheat, drawing from published studies between 1971 and 2024.

MATERIALS AND METHODS

We reviewed literature published between 1971 and 2024 retrieved from peer-reviewed journals and professional agricultural outlets, complemented with FAO and NÉBIH statistics. Search terms included "winter wheat", "foliar fertilizer/fertiliser", "micronutrient", "biostimulant", "plant growth regulator", "drought tolerance", "yield", and "protein/gluten". Studies were included if they reported field trials or relevant reviews on wheat and provided quantitative or clearly described qualitative outcomes. Non-wheat species, insufficiently documented trials, or off-topic reports were excluded.

RESULTS AND DISCUSSION

General knowledge of the cultivation of winter wheat (*Triticum aestivum* L.)

According to Kismányoky (2013), the cultivation of wheat in Hungary can be traced back to the time of the conquest of Hungary, when the Hungarians consciously cultivated wheat and made bread from it.

Winter wheat is one of the most widely grown crops in the world, with around 220 million hectares sown annually. Average yields increased globally from 2.0 t ha^{-1} in the 1960s to 3.5–4.0 t ha^{-1} in the last decade. Hungary cultivates around 1 million hectares annually, with yields fluctuating between 3 and 6 t ha^{-1} depending on year and weather. According to FAO data, global production rose from 222 million tonnes in 1961 to 770 million tonnes in 2021. National production similarly increased, though more modestly, from 1.9 to 5.3 million tonnes over the same period (*Figures 1–2*).

Fekete and Szabó (2019) found that Hungarian winter wheat production is of outstanding importance, with a clear upward trend in yield averages and a national average of 4.9 t ha^{-1} over the last 10 years. Pepó (2019) is of a similar opinion, stating that the national average yield has stagnated between 4.5 and 5.5 t ha^{-1} over several years. Koltay and Balla (1982) are of the opinion that the wheat varieties grown in the country have a potential yield of 10 t ha^{-1}, but the national yield averages are only approximately 50% of this.

Pepó (2014) concluded that wheat has a prominent role in Hungarian crop production. It is one of the most important crops cultivated in our country. Thanks to breeders, a rich portfolio of varieties is available to growers.

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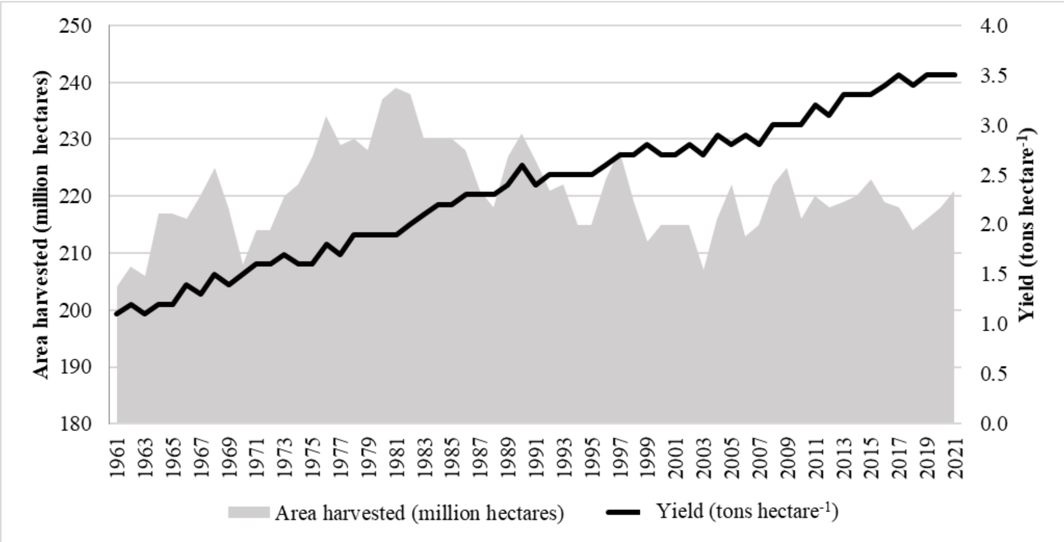
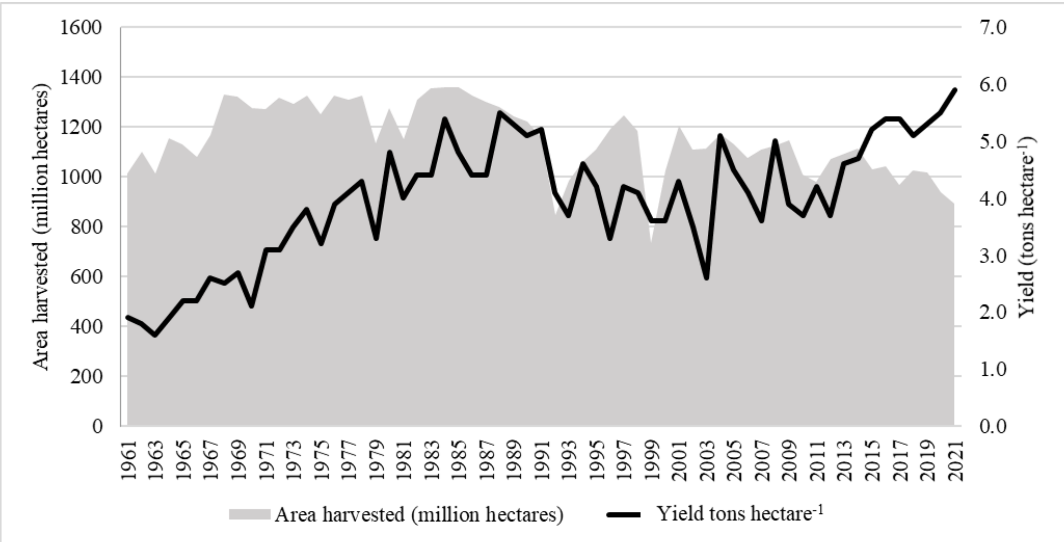
Figure 1. **Winter wheat production area and average yield in the world 1961–2021**



Source: FAO.org

Figure 2. **Winter wheat production area and average yield in Hungary 1961–2021**



Source: FAO.org

There are more than 150 officially recognised wheat genotypes in the National Catalogue of Varieties published by the NÉBIH. Compared to the 1990s, the number of winter wheat genotypes listed in the National Variety Catalogue has increased significantly. Even if we examine only the past 20 years, it is still evident that a gradually expanding variety portfolio has been available to us year after year (*Figure 3*).

Radics (2003) stated that the main objective of wheat germination is high yield and good baking quality. Pepó (2006) is of the opinion that a solution should be found to produce twice as much grain in the future with optimal quality parameters, however, arable land cannot be increased further.

Antal (2000) is of the opinion that winter wheat yields will only be satisfactory if adequate nutrient supply is ensured, since nutrient supply is of paramount importance both in terms of yield quantity and quality. According to Rouphael and Colla (2020), treatment with plant biostimulants improves crop productivity and, consequently, may also provide an alternative solution to meet the increased cereal demand of a growing population.

Puskás (2024) found that the use of foliar fertilizers and biostimulants has been increasing in recent years. According to statistics from market research company Kynetec Hungary, the proportion of foliar fertilizers and biostimulants used by farmers increased steadily between 2021 and 2023. The largest increase in use was observed in the case of cereals. Statistical data showed that in 2023, 40% of the areas sown with cereals in the cereals sector used foliar fertilisers and 18% used some form of biostimulant.

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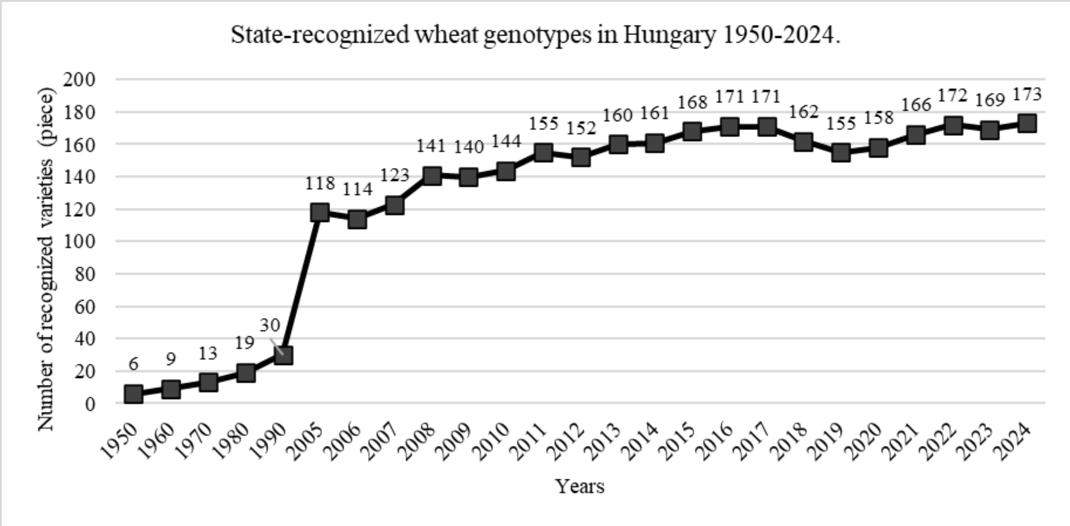
Figure 3. **Number of wheat varieties recognised by the State according to the National Catalogue of Varieties 1950–2024**



Source: NÉBIH

Review of the use of leaf fertilisers in winter wheat

As formulated by Kádár (2008), foliar fertilisation when leaves are sprayed with dilute nutrient solutions or suspensions. Leaf fertilisation is in most cases used as a supplement, usually in case of deficiency of some microelements (Fe, Mn, Zn, Cu, B, Mo). However, its effectiveness is possible if the right nutrients are added in the right way and at the right time. Leaf fertilisation usually results in a deepening of the green colour of the leaves, thus increasing their chlorophyll content and the intensity of photosynthesis.

Szakál et al. (1988) described the advantages of foliar fertilisation: rapid absorption of nutrients sprayed on the leaves, better utilisation of micro-nutrients through the leaves, complete micro-nutrient application, and the possibility of applying foliar fertilisers simultaneously with plant protection. The disadvantage is that foliar fertilisation does not allow for complete nutrient recycling and the amount of nutrient solution that can be applied at one time may be only a few percent.

Foliar fertilisation is the direct application of dilute nutrient solutions to leaves. It is particularly effective for micronutrient supply (Fe, Mn, Zn, Cu, B, Mo). Studies (e.g., Pepó and Vad, 2018) have identified optimal uptake windows across phenological phases: Fe from tillering to flowering, Mn from heading to flowering, Cu from tillering to early flowering, Zn during flowering, B during flowering, and Mo during heading. Reported outcomes include greener leaves, higher chlorophyll content, greater photosynthesis, yield increases of up to 15%, and improved grain protein content in deficient soils.

According to the information on the Genezis website, it is recommended to start foliar fertilisation of winter wheat from the phenophase of stalk emergence. Foliar fertilisation increases the yield and quality of the crop and increases the stress tolerance and disease resistance of wheat. Foliar fertilisation is the most effective way to provide micronutrients to plants and to prevent or eliminate nutrient deficiencies (https.2.)

Kalocsai et al. (2005) found zinc to be an essential nutrient for plants, actively involved in growth regulation. Tóth et al. (2018) investigated the effect of zinc carbonate foliar fertilizer on yield and nutritional parameters of winter wheat in zinc-deficient loam soils. Based on their two-year study, they found that the effect of zinc carbonate foliar fertilizer applied at tillering increased yield, crude protein content and wet-meal content and decreased starch content.

Giczi et al. (2020) conducted experiments on the effect of foliar fertilizer containing copper sulfate solution on yield and crude protein content of winter wheat in a calcareous cast substrate with low copper supply. As a result of three years of research, they found that higher yields were obtained at a dose of 0.5 kg ha^{-1} and that the best yields were obtained at 2 kg ha^{-1}. Similarly, the crude protein content is also improving with treatments. Compared to the control, 16.6% higher yields (2 kg ha^{-1}) and 10.6% higher crude protein content (4 kg ha^{-1}) can be achieved with copper foliar fertilisation.

Szakál et al. (2007) applied manganese-carbohydrate complex foliar fertilizer at four different doses (0.05; 0.1; 0.3; 0.5 kg ha^{-1}) at tillering phenophase to winter wheat stands and studied the changes in yield, gluten content and starch content. Their results showed that yield is maximum at 0.05 kg ha^{-1} and then gradually decreases with increasing dose. No significant difference was found for gluten content, while starch content increased with treatment.

Ning et al. (2023) used silicon foliar fertilizer in their experiments in winter wheat stands. They concluded that silicon foliar fertilization reduced drought stress effects.

Hoffmann (2020) found that foliar fertilizers sprayed at the time of heading or after flowering contributed mainly to yield formation. There are also foliar fertilizers containing various biostimulants.

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Spraying with such products accelerates protein synthesis and improves drought tolerance.

Review of growth regulator use in winter wheat

According to Basak (2008), even before the discovery of plant hormones, experiments had been carried out to find that the application of certain substances either accelerated or slowed down plant growth. Biostimulants do not only affect one physiological process in the plant, but can affect several life processes at the same time. Such processes may include, for example, accelerating photosynthesis, increasing the intensity of water and nutrient uptake, improving resistance.

According to Strack (2005), plant growth regulators are defined as: artificial or natural compounds that either stimulate or inhibit plant growth, Similarly, according to Mocsáni (1986), they are exogenous interventions in plant growth and development processes by chemical substances. These substances can be used to modify the life processes of plants. They can be used to influence yield, quality and growth of the plant.

According to studies by Hoffmann and Pónya (2016), biostimulants increase photosynthetic activity of plants and increase tolerance to abiotic stresses such as frost or drought, and resistance to pathogens. The most important role of biostimulants in agriculture is to produce higher quality and higher yielding products with the least possible inputs. Du Jardin (2015) found that the stress effects of global climate change can be mitigated by the use of these products.

There are three important principles regarding the effectiveness of biostimulants. The first and perhaps the most important principle is that they are most effective for the plant when it actually needs them. The second principle is important from the point of view of the farmer, who believes that biostimulants are most effective when applied at the optimum time. The third principle is that a biostimulant is most effective in terms of environmental impact when it is adapted to the energetic and physiological state of the plant in which it is to be applied.

There are many types of biostimulants, but the following are the most important:

- Amino acids and proteins, which promote plant growth and protein synthesis and accelerate stress responses.
- Humic acids and fulvic acids, which enhance nutrient uptake by plants.
- Algae extracts, which promote stress tolerance and growth of plants due to their high concentration of trace elements, minerals and plant hormones.
- Heterotrophic microbial formulations that help increase nutrient uptake.
- Vegetable extracts that stimulate the immune system of plants and stimulate photosynthesis and root development.

The most important benefits of biostimulants are that they increase the stress tolerance of plants and improve yields and crop quality (https.4.)

According to Varga (2021), amino acid preparations are most commonly used in Hungary.

According to Horváth (2019), growth regulation is considered as an essential technological element in intensive wheat production. For example, such substances can be used to reduce the height of wheat, on average by 5–15%, in order to avoid lodging. By reducing the plant height, the centre of gravity of the ears is lowered, the stalk thickens and the root mass increases. He also found that growth regulators containing the active ingredient trinepacetyl have a number of effects on the physiology of winter wheat. The effect of these active ingredients is to increase green biomass and root mass, resulting in a more stable plant. It increases the water use and nutrient uptake intensity of the plants and can increase the macro-nutrient (N, P, K) uptake by up to 15%. Their use also results in increased yields, with up to 10% more crops being produced.

Gavelieneé et al. (2018) studied the effect of biostimulants on the growth and development of winter wheat, as well as on its overwintering ability and fertility. Based on their experiments, they found that free amino acid biostimulants increased the cold tolerance of winter wheat and had a positive effect on plant growth and development. The research results of Iljkic et al. (2024) demonstrated that biostimulant had positive effects on number of grains per ear, yield, weight per hectolitre, as well as gluten and protein content.

Radzikowska et al. (2022) found that biostimulants containing amino acids, biologically derived enzymes and growth hormones resulted in an average yield increase of 8% compared to the control. In addition, they found that the thousand grain weight of the treated stand was greater than that of the untreated stand. Their research also included physiological measurements, from which they found that the treated stock showed a more favourable photosynthetic efficiency. Based on their experiments, they concluded that the biostimulants applied had a positive effect on the yield and physiological status of winter wheat, and that the preparations also significantly improved the drought tolerance of the plants.

Maignan et al. (2021) investigated the effect of a combination of a certain glutacetine biostimulant and urea or urea-ammonium nitrate fertilizer in winter wheat stands. Overall, the glutacetin-treated stock, regardless of the type of nitrogen fertilizer, had higher values for grain number per grain per ear, grain number per square meter, thus improving and increasing yield.

Al Majathoub (2004) used four different biostimulant materials in a wheat trial in Saudi Arabia. He found that all four formulations increased the resistance of wheat to environmental stresses, increased yield and improved yield quality.

CONCLUSIONS

Foliar micronutrients and growth-regulation tools can complement balanced soil fertilization to stabilize yield and improve grain quality in winter wheat,

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especially under increasing weather variability. The most consistent benefits occur when applications match phenological demand and site-specific nutrient status. However, the reviewed sources reported variable results regarding the applied doses, the timing of applications, and the genotypes examined. This variability indicates that uniform recommendations are not yet possible across different environments. Standardized dosing and reporting are therefore essential to compare effect sizes across studies. Further multi-year and multi-site investigations are required to clarify dose–response relationships, to identify optimal phenological windows, and to evaluate genotype-specific responses. Such research would enable more robust, evidence-based recommendations for farmers and strengthen the role of foliar fertilization and growth regulation in sustainable wheat production. These tools, if properly applied, may become integral components of sustainable and climate-resilient wheat production systems.

REFERENCES

Al Majathoub, M. (2004): Effect of biostimulants on production of wheat (*Triticum aestivum* L.). In: Cantero-Martínez C. (ed.), Gabiña D. (ed.). *Mediterranean rainfed agriculture: Strategies for sustainability.* Zaragoza: CIHEAM, 147–150. (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 60)

Antal, J. (2000): *Növénytermesztők zsebkönyve*, Mezőgazda Kiadó, Budapest. 392 p

Basak, A. (2008): Biostimulators – definitions, classification and legislation. In: *Biostimulators in Modern Agriculture*. General Aspects. Gawrońska H. (ed.). Warsaw. 7–17.

Du Jardin, P. (2015): Növényi biostimulánsok: definíció, fogalom, főbb kategóriák és szabályozás. *Scientia Horticulturae*, *196*: 3–14.

Fekete, Á.; Szabó É. (2019): Tápanyagpótlás őszi búzában. *AgrárUnió 20* (5), 24–26. 2019.05.22. https://www.agrarunio.hu/hirek/novenytermesztes/5135-tapanyagpotlas-oszi-buzaban

Gavelienė, V.; Pakalniškytė, L.; Novickienė, L.; Balčiauskas, L. (2018): Effect of biostimulants on cold resistance and productivity formation in winter rapeseed and winter wheat. *Irish Journal of Agricultural and Food Research, 57,* 71–83. https://www.jstor.org/stable/26555013

Giczi, Zs.; Kalocsai, R.; Vona, V.; Szakál, T.; Teschner, G.; Lakatos, E. (2020): Réz kezelések hatása őszi búza (*Triticum aestivum* L.) hozamára és nyersfehérje tartalmára. *Acta Agronomica Óváriensis Vol. 61*. No. 1. 23–32.

Hoffmann, R. (2020): Az őszi búza tavaszi trágyázásáról. *Agrofórum Online*. 2020.02.15. https://agroforum.hu/lapszam-cikk/az-oszi-buza-tavaszi-tragyazasarol/

Hoffmann, R.; Pónya, Zs. (2016): Biostimulátorok a növénytermesztésben. *Agrárium7.* Kaposvári Egyetem. 2016.09.07. https://agrarium7.hu/cikkek/713-biostimulatorok-anovenytermesztesben

Horváth, T. (2019): Az intenzív búzatermesztés gyakorlata. *Agrárium7* 2019.08.09. https://agrarium7.hu/cikkek/1556-az-intenziv-buzatermesztes-gyakorlata

Iljkić, D.; Matej, V.; Krešimir, D.; Daniela, H.; Ewa, S.; Marta, J. (2024): Variety, Chemical Protection and Biostimulator Effect on Winter Wheat Status. *Poljoprivreda 30*, br. 1: 28–35. https://doi.org/10.18047/poljo.30.1.4

Kalocsai, R.; Schmidt, R.; Szakál, P.; Giczi, Zs. (2005): A mikroelemek hatása az őszi búza minőségére. *Agro Napló IX. évf.* 2005/10. 35–38.

Kádár, I. (2008): A mikroelemkutatások eredményeiről, különös tekintettel a Cu és Zn elemekre. *Acta Agronomica Óváriensis Vol. 50.* No. 1. 9–14.

Kádár, I. (2008): A levéltrágyázás jelentősége és szerepe a növénytáplálásban. *Acta Agronomica Óváriensis Vol. 50*. No. 1. 20–27.

Kismányoky, T. (2013): *Versenyképes búzatermesztés*. Mezőgazda Kiadó. Budapest. 288 p.

Koltay, Á.; Balla, L. (1982): *Búzatermesztés és nemesítés.* Mezőgazdasági Kiadó, Budapest. 386. p.

Maignan, V.; Géliot, P.; Avice, J-C. (2021): Glutacetine® biostimulant applied on wheat under contrasting field conditions improves grain number leading to better yield, upgrades n-related traits and changes grain ionome. *Plants; 10*(3):456. https://doi.org/10.3390/plants10030456

Mándy, Gy. (1971): *Hogyan jöttek létre kultúrnövényeink?* Mezőgazdasági Kiadó. Budapest. 243 p.

Mocsán, L. (1986): Növekedésszabályozás a szántóföldi növénytermesztésben. Zalaegerszeg.

Ning, D.; Zhang, Y.; Li, X; Qin, A.; Huang, C.; Fu, Y.; Gao, Y.; Duan, A. (2023): The effects of foliar supplementation of silicon on physiological and biochemical responses of winter wheat to drought stress during different growth stages. *Plants; 12*(12):2386. https://doi.org/10.3390/plants12122386

Pepó, P. (2006): *Búzavertikum aktuális kérdései.* Center-Print Nyomda. Debrecen. 177 p.

Pepó, P. (2014): Néhány gondolat a magyar búzatermesztés helyzetéről és lehetőségeiről. *Agroinform, XXIII*. évf. 6. szám 12–13.

Pepó, P.; Vad, A. (2018): Az őszi búza tápanyagigénye. *Magyar Mezőgazdaság, 73* (10), 16–18. 2018.03.07. https://magyarmezogazdasag.hu/2018/03/07/az-oszi-buza-tapanyagigenye/

Pepó, P. (2019): Közönséges búza. 11–58. In: *Integrált növénytermesztés 2.* Alapnövények. (Szerk. Pepó P.) Mezőgazda Lap- és Könyvkiadó, Budapest. 359 p.

Puskás, P. (2024): Lombtrágya és biostimulátor: mennyi fogy hazánkban? *Magyar Mezőgazdaság.* 2024.08.12. https://magyarmezogazdasag.hu/2024/08/12/lombtragya-es-biostimulator-mennyi-fogy-hazankban/

Radics, L. (2003): *Szántóföldi növénytermesztés*. Szaktudás Kiadó Ház Zrt. Budapest. 77. p.

Radzikowska-Kujawska, D.; John, P.; Piechota, T.; Nowicki, M.; Kowalczewski, Pł. (2023): Response of winter wheat (*Triticum aestivum* L.) to selected biostimulants under drought conditions. *Agriculture. 13*(1):121. https://doi.org/10.3390/agriculture13010121

Rouphael, Y.; Colla, G. (2020): Editorial: Biostimulants in agriculture. *Front. Plant Sci. 11*, 40. DOI: 10.3389/fpls.2020.00040

DOI: 10.34101/ACTAAGRAR/2/15270

Starck, Z. (2005): Stosowanie regulatorów wzrostu oraz biostymulatorów w uprawie roślin. Rolnik Dzierżawca. Luty.74-76.

Szakál, P.; Schmidt, R.; Barkóczi, M. (1988): Experiments for agricultural utilization of copper containing wastes. World Conference on Hazardous Waste, Elsevier Science Publishers, Amsterdam. 1361–1365.

Szakál, P.; Barkóczi, M.; Giczi, Zs. (2007): Bioetanol-előállítás céljára termesztett búza Mn-trágyázása. *Acta Agronomica Óváriensis Vol. 49*. No. 2. 589–594.

Tóth, E.A.; Kalocsai, R.; Dorka-Vona, V.; Szakál, T. (2018): A Zn-lombrágyázás hatása az őszi búza főbb értékmérő tulajdonságaira. *Acta Agronomica Óváriensis Vol. 59.* No. 1. 4–12.

Varga, L. (2021): Biostimuláns: Divat vagy szükséglet? *Kertészet és Szőlészet, 70*(39): 19.

http.1.: NÉBIH https://portal.nebih.gov.hu/-/nemzeti-fajtajegyzekek Letöltés: 2024.11.

https:2.: Genezis https://genezispartner.hu/novenykulturak/szantofoldi-novenyek/oszi-buza/ Letöltés: 2024.11.

https.3.: Biostimulátorok hatékonysága https://www.profeed.hu/hirek/szakcikkek/biostimulatorok-lehetoseg-a-novenyvedosok-es-novenyorvosok-kezeben Letöltés: 2024.11.

https.4.: Biostimulátorok fajtái https://agrobio.hu/hu/hirek-archivum/termeszetes-eroforrasok-a-biostimulatorok-szerepe-a-fenntarthato-mezogazdasagban/ (Természetes erőforrások – a biostimulátorok szerepe a fenntartható mezőgazdaságban. 2023.06.10. Agro bio.) Letöltés: 2024.11.