PHYSIOLOGICAL CHARACTERISTICS OF WHEAT CULTIVARS TREATED WITH SOIL BACTERIA IN A SMALL-PLOT EXPERIMENT

TALAJBAKTÉRIUMOKKAL KEZELT ŐSZI BÚZA FAJTÁK FIZIOLÓGIAI SAJÁTOSSÁGAI KISPARCELLÁS KÍSÉRLETBEN

RÉKA LÁPOSI – ANNA FRUZSINA DUDÁS – SZILÁRD ZSOLT TÓTH – RITA TURY – ILDIKÓ BÉLTEKI
laposi.reka@uni-mate.hu

Abstract

This paper presents the results of small-plot field experiment conducted in 2022, a year of severe drought, with soil bacteria-treated wheat cultivars, during which we examined photosynthetic pigments, average yield, and certain quality parameters using in vivo methods. The soil microbe preparation used is especially recommended for use in warn, drought period, and it is also effective for seed treatment. Its use can be expected to result in better nutrient and water supply, more homogeneous stands, and increased stress tolerance. At the beginning of flowering, the SPAD, EVI, RDVI indices, which indicate chlorophyll content in leaves were significantly higher in three varieties (Mv Nemere, Mv Kondás, Mv Pelsodur), while at the same time, these varieties showed higher photochemical activity (PRI), lower stress sensitivity (SIPI), and lower carotenoid content (CRI). Water content was higher in treated individuals for all varieties. For all 8 varieties, the average yield was approximately 10% higher on the treated plots, Mv Nemere. The nutritional values were only of medium quality, but all quality parameters on the treated plots showed better results. The quality parameters indicated only medium quality, but we obtained better results for all quality parameters on the treated plots. Overall, it can be said that the product can be used effectively even in a drought year, but at the higher dose recommended by the manufacturer.
Keywords: *wheat cultivars, soil bacteria, photosynthetic pigments, vegetation indices, yield, grain quality*
JEL code: *Q19*

Összefoglalás

Jelen munka a 2022-es erősen aszályos év talajbaktériummal kezelt búza fajtákkal végzett kisparcellás kompolti kísérlet eredményeit mutatja be, mely során in vivo módszerekkel vizsgáltunk fotoszintetikus paramétereket, illetve a termésátlagot és egyes beltartalmi jellemzőket. A felhasznált talajmikróba készítmény kifejezetten a meleg, aszályos időszakokban ajánlott alkalmazni, emellett hatékony a vetőmagok csávázásra is. Használatával jobb tápanyag- és vízellátottság, homogénebb állomány és fokozott stressztűrő-képesség várható. A virágzás kezdetén, a klorofill-tartalmat jelző SPAD, EVI és RDVI indexek 3 fajtánál volt szignifikánsan magasabbak (Mv Nemere, Mv Kondás, Mv Pelsodur), ezzel párhuzamosan ezen fajoknál magasabb fotokémiai aktivitást, (PRI), alacsonyabb stresszérzékenységet (SIPI) és kevesebb fényvédő karotinoid-tartalmat (CRI) mértünk. A víztartalom minden fajta esetében

magasabb volt a kezelt egyedeknél. A kontrol és a kezelt parcellákban mért termésátlag egyaránt meghaladta a megyei szintet abban az évben, és mind a 8 fajta esetében a kezelt parcellákon volt magasabb érték, de az eltérés - az Mv Nemere kivételével - nem volt több 10%-nál. A beltartalmi értékek csak közepes minőséget jeleztek, bár nem standard mérési módszerrel határoztuk meg, viszont a kezelt parcellákon minden minőségi paraméter esetében jobb eredményt kaptunk. Összességében elmondható, hogy aszályos évben is eredményesen alkalmazható a készítmény, viszont a gyártó által javasolt magasabb dózisban.
Kulcsszavak: *búza fajták, talajbaktériumok, fotoszintetikus pigmentek, vegetációs indexek, termésátlag, minőségi paraméterek*

Introduction

The challenge facing agriculture today is not only to increase crop yields and quality, but also to achieve this while carefully managing the natural resources used for cultivation and, where possible, using environmentally friendly methods. The most effective way to achieve this is to select cultivars that are suitable for the given landscape and best adapted to local conditions, and choosing environmentally friendly, complex nutrient replenishment methods that ensure the sustainable, long-term use of the soil while allowing the genetic potential of the given cultivar to be realized (KUMMERER et al. 2010).

One environmentally friendly method of nutrient replenishment is the reintroduction of soil microbes into the soil, which can also be used in organic farming. Microorganisms living in the soil have numerous beneficial effects on cultivated plants. They enhance the decomposition of organic matter in the soil and promote nutrient uptake by plants, as their metabolism makes these nutrients available in an absorbable form. They bind nitrogen in the air and store it, thereby increasing the nitrogen base of the soil. Microbes provide protection against pathogens that attack germinating seeds and seedlings, on the one hand through more effective competition and on the other hand through the production of antibiotics (MAKÁDI, 2010). These organisms also have an impact on the condition of the soil and its physical, chemical, and various biochemical processes. As a result of these processes, the structure and water management capacity of the soil, as well as its ability to provide nutrients, vary greatly between different soil types (KÁTAY and SÁNDOR, 2011).

In Hungary, many soil microbe products are available for farmers. In our current work, we examined the effects of a soil microbe product (Mikor-Vital Supary, Bio-Nat Kft.) - that was awarded an Innovation Grand Prize (2020) - on the physiological parameters of eight wheat varieties. We investigated some photosynthetic parameters and protective pigments at the beginning of flowering, moreover the average yield and crop quality at harvest time, since we expected differences in these parameters as a result of the treatment. We applied *in vivo* methods (e.g., ground-based remote sensing) that allow us to get a lot of data, even on a field scale without damaging the plants.

Material and methods

Study site and technological parameters

The experimental area is located in Kompolt research site, which has more than 100 years of experience in plant breeding. Nowadays it is an experimental farm of Hungarian University of Agriculture and Life Sciences, formerly it was the Rudolf Fleischmann Agricultural Research Institute. The experimental site is located on the southern side of the Mátra Mountains, between

Eger and Gyöngyös, 125 meters above sea level, in the rain shadow of the North Central Mountains. Its climate is moderately warm with variable precipitation, moreover with harsh snow-free winters and dry summers. These attributes provide an excellent background for the breeding of resistant, drought-tolerant plants (HOLLÓ et al. 2009).

In Kompolt, most of the area is characterized by non-carbonate chernozem forest soil formed on loess clay containing sedimentary andesite debris, with a relatively deep humus layer (50-80 cm) but low humus content (2.6%). The topsoil is acidic (pH_{KCl} 4.8), heavily leached without lime content ($CaCO_3$ 0%). The subsoil is compact, less acidic (pH_{KCl} 6.6) and even alkaline at a depth of 130-150 cm. The soil structure is not optimal, relatively difficult to cultivate, and heavily cracked on the surface, which causes a lot of water to evaporate from it. However, with the right agricultural techniques, it can store sufficient amounts of water, which is important because the groundwater is located at a depth of 10-12 m. For this reason, the amount and distribution of precipitation plays a decisive role in crop production, nutrient uptake, and soil microbe activity (KÁDÁR and HOLLÓ 2006; HOLLÓ et al. 2009; TÓTH 2011).

In 2022, there was a very serious drought in the country (Website 1), which caused severe damage to agricultural production (Website 2). Table 1 clearly shows that precipitation in the experimental area during the growing season was 50% lower than the average for the past 30 years. The difference was particularly large in May (77%) and June (76%), which is a critical period for flowering, fertilization, and fruit formation. This is not only an important factor in terms of crop yield and quality, but it can also influence the activity of soil microbes introduced into the soil.

Table 1. Climatic parameters during the growing season in 2021 and 2022

2021/2022	Daily total precipitation [mm]	Average precipitation of 30 years [mm]	Difference %
September	9.8	42.8	+88
October	8.6	36.6	+71
November	62.9	45.9	+37
December	38.5	39.6	-3
January	1.5	30.6	-95
February	8.9	31.4	-72
March	19.9	28.9	-32
April	48.1	41.9	+14
May	14.5	62.9	-77
June	24.8	71.4	-76
July	14.3	74.4	-81
Total	251.8	506.4	-51

Source: Research Site (Kompolt, MATE)

Since 2015, the area has also been home to numerous nutrient replenishment experiments, seeking environmentally friendly methods suitable for the characteristics of the region. The results of these experiments play a key role in our consulting activities. In the course of our work, we have tested several domestically produced soil microbe preparations and plant conditioners in large and small-scale experiments on a number of arable crops. In this paper, I present the results of the 2022 small-plot Mikro-Vital Supary treatment, in which we examined certain physiological parameters of winter wheat varieties at the beginning of ear emergence (22nd of May 2022) and at harvest (21st of July 2022).

The cultivar comparison experiments were set up every year in the so-called internal breeding garden (47°44'18.45" N, 20°14'03.95" E), which also played an important role in the annual cultivar demonstration shows in June. In our experiment, we examined eight popular domestic wheat varieties: Mv Nemere, Mv Nádor, Mv Ménrót, Mv Krajcár, Mv Kolo, Mv Felleg, Mv Kondás, and Mv Pelsodur (Figure 1). We divided the 34.5 m^2 plots into two parts, treating one half with Mikro-Vital Supary at a dose of 1 L ha^{-1} at sowing (5th of October 2021). Before sowing (29th of September 2021), all plots received basic fertilizer (NPK 10-20-10, 250 kg ha^{-1}), both the Mikro-Vital and the control plots. Weed control took place on 22nd of April 2022, and fungicide and insecticide treatments were also carried out on the same day. Harvesting took place on 21st of July 2022.

Figure 1. Small plot variety trial of wheat cultivars treated with Mikro-Vital Supary (22th of May 2022)

Features of the soil microbe product used in the experiment

The first product of the microbial biofertilizer used in our experiment was developed in 1997 by Bio-Nat Kft. (Website 3). The various products contain a combination of bacterial strains that essentially make the nutrients in the soil available to plants, enhance rooting and stress tolerance, and provide protection against a number of pathogenic organisms. The current members of the product family are recommended not only for arable crops but also for horticultural crops. The Mikro-Vital Supary we tested was a relatively new product (Innovation Granx Price in 2020) that is ideal for use in dry and hot conditions and can also be used as a supplement for seed coating. The species it contains (*Bacillus subtilis, Bacillus aryabhattai, Paenibacillus peoriae*) are the most resistant to environmental influences due to their endospore-forming properties. The product effectively mobilizes minerals, is also suitable for stem decomposition, and provides protection against a number of pathogenic microorganisms by displacing soil pathogens from the root zone. The product can also be used in organic farming. It should be applied before sowing or during sowing, added to the row together with the seed coating material. It must be worked into the soil in all arable and horticultural crops. The recommended dose is 1-3 L ha^{-1}, which should be applied with 40-500 L ha^{-1} of water, depending on the application equipment. The product was applied directly to the surface of the seeds at a dose of L ha^{-1} during sowing (21st of September 2021).

Applied wheat cultivars and their main characteristics

- *Mv Nemere:* state recognition in 2013, Agricultural Innovation Prize in 2018, autumn sown variety (5-20 of October), high-yielding potential: 9-10 t ha^{-1}, good baking quality, excellent straw strenght, good winterhardiness (Website 4).
- *Mv Nádor:* state recognition in 2012, excellent yield-potential: 10-11 t ha^{-1}, short height, good tillering, excellent lodging-resistance, outstanding frost-resistance, autumn sown (5-20 of October) (Website 5)
- *Mv Ménrót:* excellent yield potential and disease (rust)-resistance (rust, *Fusarium*, powdery mildew), good winter-hardiness and lodging-resistance (Website 6). In 2019 its yield was 9.36 t ha^{-1} Kompolt Research Area.
- *Mv Krajcár:* excellent yield potential and lodging resistance (7-9 t ha^{-1}), drought-tolerant, fungal disease tolerant (Website 7).
- *Mv Kolo:* state recognition in 2006 (also in Romania and Croatia), resistance to *Fusarium* is better than average, good yield potential: 6-8 t ha^{-1} (Website 8).
- *Mv Felleg:* high yield potential (8.5-9.5 t ha^{-1}), excellent winter hardiness and lodging resistance, outstanding tolerance to stem rust (Website 9).
- *Mv Kondás:* average yield: 9.0-11.0 t ha^{-1}, lower protein and gluten content than milling wheat varieties with good baking quality, excellent disease-resistance (Website 10).
- *Mv Pelsodur:* early durum variety, high yellow pigment content, strong gluten structure (excellent for dry pasta production), resistant to several pathogens, average yield: 7.0-8.0 t ha^{-1} (Website 11)

Physiological measurements

The aim of the Micro-Vital treatment was to increase the productivity of the varieties, if possible, the yield quality, but also indirectly the stress tolerance, so that the plants can produce biomass according to their genetic potential even under adverse weather conditions.

The effect of the treatment is most clearly shown by the average yield at harvest and the freshly determined quality parameters. However, it is worthwhile to verify the effectiveness of the treatment at an earlier stage of the growing season, to get an idea of the most important physiological processes of the plants, photosynthesis, stress sensitivity, so that, if necessary, intervention can be made to achieve optimal yields (nutrient supplementation, irrigation, plant protection). Therefore, at the onset of flowering (anthesis), the parameters determining biomass formation, as photosynthetic pigment content and composition, leaf water content, stress sensitivity, and the amount of protective pigments accumulated in response to stress were studied in control and treated plots.

For this purpose, in vivo methods such as SPAD-index determination or reflectance analysis by ground remote sensing were used to calculate spectral vegetation indices that can be related to these physiological variables. We selected 10 individuals in each plot, covering the entire length of the plot, and measured the leaves below the flag leaf on each plant in the upper third part at the beginning of flowering (22nd of May 2022). The SPAD 502 device (Konica, Minolta, Japan) determines the relative chlorophyll content of leaves and provides a value between 0 and 100 without a unit of measurement. The measurement surface is very small (0.06 cm^2), thus it is important to place the leaves on a similar site for each measurement, as even a leaf vein or a spot can significantly alter the value. The instrument measures the absorbance of leaves at 650 nm and 940 nm wavelength (in the red and infrared ranges) and calculates the index (GITELSON and MERZLYAK 2004). Due to the high nitrogen content of chlorophyll, this index is also used in agriculture to estimate the nitrogen supply of plants, and due to the role of chlorophyll in photosynthesis, it is also applied to characterise biomass production capacity (RAJCAN et al. 1999; ARREGUI et al. 2006). Chlorophyll determination using SPAD is a fast, non-invasive measurement method and generates large amounts of data from a large area in a relatively short time.

Similarly, ground-based remote sensing, which measures the reflectance of leaves, provides a large amount of field data that can be used to generate spectral vegetation indices that provide information on a number of physiological parameters. These are also frequently used in agricultural practice worldwide to assess the health status of individual crops. One such device is the ASD FieldSpec3 portable spectroradiometer, which measures light transmitted through leaves and reflected from leaves using different detectors (STAMP and BOONE 1989). Each detector senses different wavelength ranges: VNIR (350-1000 nm); SWIR1 (1000-1830 nm); SWIR2 (1830-2500 nm). The front optics used provided a viewing angle of 8° (ASD, 2007). Before the measurement, we calibrated the instrument with a Spectralon panel with known reflectance. During the measurement, the individual spectra were recorded in relation to this reference value. Each measurement consisted of recording three spectra, the first of which was disregarded in order to avoid measurement errors. The measured spectra were converted into reflectance values using ViewSpecPro software, from which the spectral vegetation indices were calculated in Microsoft Excel based on the equations given in Table 2. The vegetation indices obtained provide information on physiological parameters such as the chlorophyll, carotenoid, anthocyanin, and water content of leaves, as well as photochemical efficiency and stress sensitivity (ZARCO-TEJADA et al. 2005). The measurements were taken in clear, sunny weather, as we measured the radiation reflected from the leaves, which is determined by the internal content of the leaves. Hundreds of spectral vegetation indices have been published (GARCIA-ROMERO et al. 2017). From these, we selected those that have already been used in agricultural practice to characterize the physiological characteristics of certain crops (AGAPIOU et al. 2012; SANKARAN et al. 2015; GABRIEL et al. 2017).

Table 2. Applied vegetation indices and related physiological parameters based on measurements by ASD FieldSpec 3 instrument

Structural indices – chlorophyll	**Formulae**	**References**
Normalized Difference Vegetation Index (NDVI)	$(R_{800}-R_{670})/(R_{800}+R_{670})$	Rouse et al. (1974)
Renormalized Difference Vegetation Index (RDVI)	$(R_{800}-R_{670})/((R_{800}+R_{670})^{0,5})$	Rougean and Breon (1995)
Enhanced Vegetation Index (EVI)	$2.5\times(R_{840} - R_{670})/(R_{840} + (6\times R_{670}) - (7.5\times R_{450}) + 1)$	Huete et al. (2002)
Leaf pigments		
Carotenoid Reflectance Index (CRI)	$1/R_{550}-1/R_{700}$	Gitelson et al. (2002)
Anthocyanin Reflectance Index (ARI)	$R_{840}\times(1/R_{550}-1/R_{700})$	*Gitelson et al. (2001)*
Stress sensitivity – carotenoid/chlorophyll ratio		
Structure Insensitive Pigment Index (SIPI)	$(R_{800}-R_{445})/(R_{800}-R_{680})$	Peñuelas et al. (1995)
Light use efficiency – xanthophyll index		
Photochemical Reflectance Index (PRI)	$(R_{550}-R_{570})/(R_{550}+R_{570})$	Gamon et al. (1997)
Water content of leaves		
Plant Water Index (PWI)	R_{970}/R_{900}	Peñuelas et al. (1997)
Simple Ratio Water Index (SRWI)	R_{858}/R_{1240}	*Zarco-Tejada et. al. (2003)*

Source: ZARCO-TEJADA et al. (2005)

At harvest time (21st of July 2022), the yield was recorded for each plot, from which we calculated the average yield per hectare. Approximately half a kilogram of grain was used for quality testing, which was performed using a FOSS Infratec 1241 Grain Analyzer. The gluten and protein content were expressed as a percentage, the W value in J, and the Zeleny index in ml. The values obtained were compared with the values corresponding to the various standards, and the wheat varieties were classified on this basis (Table 3).

Table 3. Quality categories and requirements of wheat (The method for determining this is specified in standard MSZ EN ISO 27971:2015)

Quality parameters	Method	Quality requirements			
		Quality category I	Quality category II	Quality category III	Quality category IV
Raw protein content min. (N*5,7)(%)	MSz.6367-11:84	14	13	11.5	10.5
Gluten content min. (%)	MSz.6367-12:87	30	28	26	-
W-value min. (10^{-4} Joule)	ISO 5530-4:2003	250	200	150	-
Zeleny-index min. (ml)	MSz. ISO 5529:93	50	45	35	-

Source: Website 12

In the case of yield and quality parameters, only average samples were available for each plot. SPAD values and spectral vegetation indices were measured in 10 replicates, allowing for statistical evaluation of the effects of treatment using one-way analysis of variance (ANOVA) and Tukey's b test (SPSS 20.0).

Results

Pigment composition and water content of leaves at the beginning of flowering

The amount and ratio of photosynthetic pigments (chlorophylls and carotenoids) and the water content of leaves are decisive factors in biomass formation. By examining these factors well before harvest, the effects of treatments can already be assessed at certain stages of plant development. Since the intensity of photosynthesis is highest at the beginning of flowering, we examined the pigment composition of the leaves during this period.

The SPAD value is a relative measure of the chlorophyll content of plants. Chlorophylls play a role in collecting light energy and converting it into chemical energy. As key pigments in photosynthesis, they directly determine the biomass production potential of plants (CURRAN et al. 1990). Due to their high nitrogen content, their quantity is also indirectly suitable for estimating plant nutrient supply (nitrogen content) (FILELLA et al. 1995, MORAN et al. 2000). As they are very sensitive to adverse environmental factors (high light intensity, UV-B, drought, high temperature), they are closely related to stress sensitivity and influence leaf aging, as they break down in leaves faster than carotenoids, which also have light-collecting and antioxidant functions (PEÑUELAS and FILELLA 1998, MERZLYAK et al. 1999).

In our experiment, the standard deviations of SPAD values were relatively high, as we had observed in our previous large-scale experiments (LAPOSI et al., 2020). The treatment resulted in significant increase of SPAD-value only in this case in the case of Mv Nemere (14%), Mv Kondás (15.6%), and Mv Pelsodur (6.5%). In the leaves of Mv Nemere and Mv Kondás, the SPAD value was above 50, which is higher than what SZILÁGYI (2013) measured with N_{120}+PK treatment in the case of GK Öthalom (45) and GK Csillag (49). In SUGÁR's (2014)

3-year nutrient replenishment experiments, the maximum SPAD value in flag leaves measured was 53 for Mv Verbunkos, 51 for Mv Palotás, and 50 for Mv Toborzó.

In the case of wheat, the normalized vegetation index (NDVI) and SPAD value are widely used to estimate expected yield and grain quality as indicators of N supply (KIZILGECI et al., 2024).

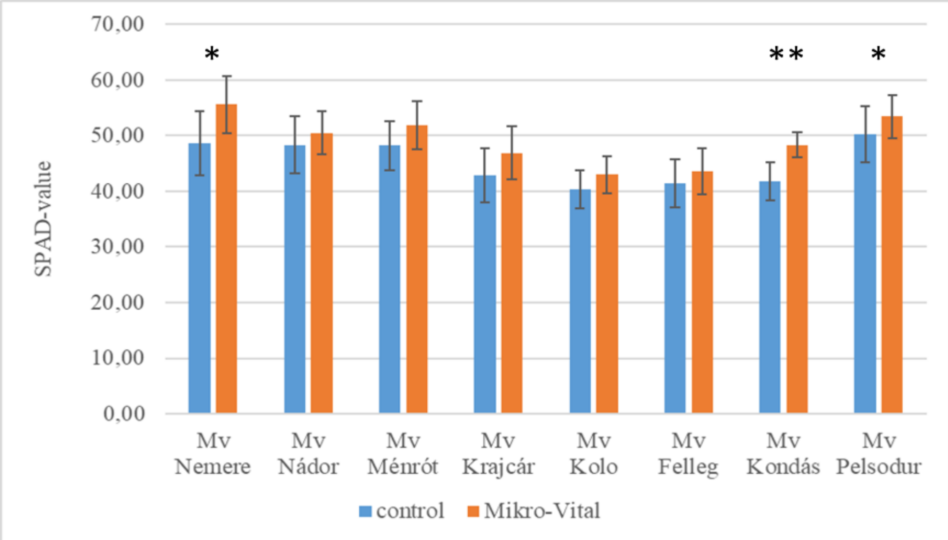

Figure 2. Relative chlorophyll content (SPAD-value) of wheat cultivars at the beginning of flowering (Mean+SD, n=10; 22/05/2022)

*(Note: ANOVA significance: **-p<0.01; *-p<0.05)*

Among the vegetation indices calculated from leaf reflectance, RDVI and EVI, in addition to NDVI, can also be correlated with leaf chlorophyll and nitrogen content. RDVI and EVI are transforms of classical indices as NDVI and Simple Ratio (SR) in order to linearize the relationships with vegetation biophysical parameters while minimizing soil and atmosphere influences (Xing et al. 2019). As can be seen from Table 4, indices including NDVI, RDVI and EVI exhibited significantly higher value in Mv Nemere leaves. The effect of treatment was detectable in three varieties (Mv Kondás, Mv Krajcár, Mv Pelsodur) by the RDVI and EVI indices, while only NDVI indicated higher chlorophyll content in Mv Kolo leaves. Chlorophyll-related vegetation indices of Mv Felleg performed no significant difference between treated and control plants.

In many cases, higher chlorophyll content is associated with higher photochemical efficiency, as indicated by the PRI index. This was higher in the treated individuals in the case of Mv Nemere, Mv Nádor, Mv Krajcár, Mv Kondás, and Mv Pelsodur (Table 4). The PRI index is inversely proportional to the amount of photoprotective pigments (xanthophylls) and the intensity of the membrane protection mechanism (xanthophyll cycle) performed by them (GAMON et al. 1997). In addition to higher photochemical efficiency (PRI), plants have lower stress sensitivity in a given environment, as indicated by a lower SIPI index (PEÑUELAS et al. 1995). This was only significantly lower in treated individuals in the case of Mv Nemere, Mv Kondás, and Mv Krajcár. Different stress conditions enhance carotenoid and/or anthocyanin accumulation of plants (PIETRINI et al 2002), as due to their antioxidant properties can protect various cell structures from damage. The results show that carotenoids had higher significance in protective processes in Mv Ménrót, Mv Kolo, Mv Felleg, and Mv Pelsodur leaves, while Mv Krajcár was characterized by higher anthocyanin content in the control plots as Table 4 indicates.

Adequate water content in leaves is essential for photosynthesis and other metabolic processes. The PWI and SRWI indices are most commonly used to estimate leaf water content, although these are strongly influenced by leaf structure, dry matter content and LAI, as well as the age of the individuals (SERRANO et al. 2000, ZARCO-TEJADA and USTIN, 2001). The PWI index was higher in treated plants of all cultivars, except Mv Felleg, moreover the SRWI index showed no significant difference only in Mv Felleg and Mv Kolo as shown in Table 4.

Table 4. Statistics of spectral vegetation indices in wheat leaves before flowering (Mean+SD, n=10; 22/05/2022)

Vegetation indices/ cultivars	NDVI	RDVI	EVI	PRI	SIPI	CRI	ARI	PWI	SRWI
MV Nemere	*↑	***↑	***↑	*↑	*↓	ns	ns	**↑	**↑
MV Nádor	*↑	ns	ns	***↑	ns	ns	ns	***↑	**↑
MV Ménrót	**↑	ns	ns	ns	ns	*↓	ns	***↑	**↑
MV Krajcár	ns	*↑	*↑	*↑	*↓	ns	*↓	***↑	**↑
MV Kolo	ns	ns	*↑	ns	ns	**↓	ns	*↑	ns
MV Felleg	ns	ns	ns	ns	ns	*↓	ns	ns	ns
MV Kondás	ns	*↑↑	***↑	*↑	*↓	ns	ns	***↑	***↑
MV Pelsodur	ns	*↑	*↑	*↑	ns	*↓	ns	***↑	***↑

*(Note: ANOVA significance: *-p≤0,05); **-p≤0,01; ***-p≤0,001, ns-not significant; Arrow direction: ↑ - significantly higher and ↓ - lower value in treated individuals than in the control group)*

Yield and grain quality at harvest

Previous large-plot experiments applied Mikro-Vital preparations in multiple doses and at different application times (KAPRINYÁK et al., 2018). It was found that even a dose of 1 L ha^{-1} caused a significant increase in average yield, but 2 L ha-1 did not increase the yield significantly. Therefore, only the 1 L ha^{-1} dose was used in the smallplot experiment. In the current experiment, the average yield was higher for all varieties on the treated plots, but this difference did not exceed 10%. The largest difference (7% increase) was measured for Mv Kondás, followed by Mv Nádor with 6.5%, and the smallest difference was for Mv Pelsadur (0.8%). For the other varieties, the difference ranged between 2 and 4% (Figure 3).

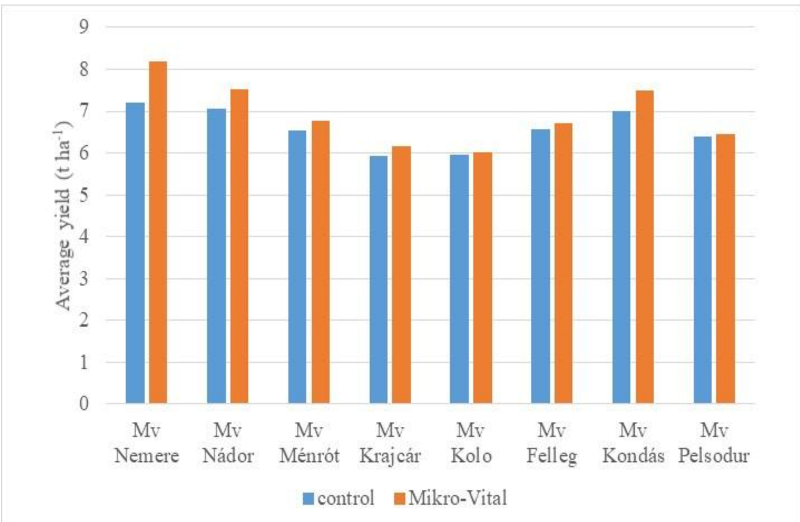

Figure 3. Average yield of winter wheat in small-plot experiment (21/07/2022)

According to data from the Hungarian Central Statistical Office the average wheat yield was particularly low in 2022. There has not been such a low value in the last 10 years: the national average was 4.4 t ha^{-1} (26% lower than in the previous year), while in Heves County it was only 3.4 t ha^{-1}, which has been unprecedented for 10 years. (Website 12). This may be due to the amount and distribution of precipitation during the given growing season. During the 2021-2022 growing season, annual precipitation was 51% lower than the 30-year average. It is worth noting that precipitation in January was 95%, in February 22%, in May during flowering 77%, and in June during the harvest period 76% lower than the 30-year average (see Table 1).

In contrast, the agricultural techniques used in the small-plot experiments enabled tested wheat varieties to produce yields above the county and national averages. Since we only obtained one data point per plot, we were unable to perform statistical tests, but all wheat varieties produced higher yields on the treated plots. Mv Nemere, Mv Kondás and Mv Nádor produced the highest average yields (above 7.5 t ha^{-1}), and this is where the greatest difference compared to the control was observed: 13.7, 7.1, 6.5%, respectively.

Table 5 shows that the quality parameters of treated individuals were also better, although they only the third-class quality in several parameters. Since we obtained average samples from each plot here as well, we were unable to perform statistical tests.

Table 5. Grain quality parameters of wheat cultivars measured by FOSS Infratec Grain Analyzer (21/07/2022)

	Protein content %		**Gluten content %**		**W-value (J)**		**Zeleny-index (ml)**	
	control	MV	control	MV	control	MV	control	MV
Mv Nemere	9.0	10.8	18.8	23.5	86.7	143.2	29.8	40.8
Mv Nádor	8.4	9.9	18.7	21.8	103.5	139.4	20.5	28.7
Mv Ménrót	8.8	10.5	16.1	22.4	72.1	131.2	30.6	38.4
Mv Krajcár	8.2	10.7	19.3	23.8	85.9	156.3	26.0	36.4
Mv Kolo	10.1	12.0	20.7	25.1	111.9	164.6	37.3	45.5
Mv Felleg	9.4	12.1	18.4	25.5	94.1	163.3	33.7	46.4
Mv Kondás	8.5	11.8	13.4	24.2	68.7	163.3	30.9	44.9
Mv Pelsodur	10.6	12.8	24.3	27.8	106.6	169.6	43.0	46.5

Protein content is one of the most important quality characteristics of wheat, which is of paramount importance in terms of both nutritional value and end use (VERAVERBEKE and DELCOUR, 2002). The protein content of medium-quality (third-class) wheat is between 11.5 and 13.0% on a dry matter basis (JOLÁNKAI and SZABÓ 2005, KAJDI 2011). Only Mv Kolo, Mv Felleg and Mv Pelsodur achieved this value. The most significant increase was measured in the case of Mv Kondás (38%), Mv Krajcár (30%) and Mv Felleg (28%), but even the smallest increase was 17% (Mv Nádor).

The amount of gluten is measured in wheat flour after washing out the soluble components; this is the remaining hydrated protein matrix that is insoluble in water. Its value is usually between 20 and 40%. (POLLHAMERNÉ 1981). The gluten content reached 20% in only two wheat varieties in the control plots (Mv Kolo, Mv Pelsodur), but exceeded this value in all varieties in the treated plots. The most significant increase was also measured in Mv Kondás (80%), and the smallest in Mv Nádor (17%). Only Mv Pelsodur reached quality category II.

The W value expresses the energy required to deform the dough (in joules) (RASPER et al. 1986). For medium-quality wheat (third-class), the W value ranges from 180 to 250, while for high-quality wheat it is above 250 (JOLÁNKAI and SZABÓ 2005). None of the wheat varieties tested reached medium quality, not even on the treated plots (except for the treated Mv Talentum triticale), although a significant improvement was measured compared to the control plots: 137% for Mv Kondás, 81% in the case of Mv Ménrót and Mv Krajcár. The smallest difference was observed in the case of Mv Kolo (47%) and Mv Nádor (34%). According to some literature, wheat varieties with a deformation energy value of 160-250 J already belong to the first category (Website 13). Based on his, four of the wheat varieties tested (Mv Kolo, Mv Kondás, Mv Felleg, Mv Pelsodur) reached a value of 160 on the treated plots.

The Zeleny index, or sedimentation value, also provides information about the quality of the gluten. The method was developed by ZELENY in 1947, and its essence is that gluten proteins swell in an acidic environment, and the increase in volume expressed in ml is proportional to the quality of the flour. A higher value indicates better quality. The maximum value can be 100, above 50, we are talking about quality category I (BÉLTEKI 2019). None of the varieties achieved this value, not even on the treated plots. The highest value was produced by Mv Pelsodur and Mv Felleg (46), while the lowest was achieved by Mv Nádor (28). The greatest differences were observed in Mv Talentum (70%), Mv Kondás (45%), Mv Krajcár (40%) and Mv Nádor (40%) leaves.

These values were probably also influenced by the technique applied (Infratec Grain Analyser) which differs from the method described in the standard. Nevertheless, we find the instrument suitable for comparing treated and control plants. Overall, Mikro-Vital Supary treatment had a positive effect on all four parameters studied, despite the wheat cultivars achieved only medium quality on the poorly fertile soil of the experimental area in a drought year.

Conclusion

In 2022, a severe drought caused enormous damage to agricultural crops, which did not spare autumn-sown cereals either. Autumn wheat yields were at their lowest level in 10 years, falling nearly 30% below the national average compared to the previous year (Website 2). The Kompolt experimental area is particularly prone to drought, with low rainfall and unpredictable distribution. In addition, crop production is further hampered by unfavourable soil conditions. For this reason, the area is ideal for breeding stress-tolerant varieties and testing various yield-enhancing substances and plant conditioners.

The yield on each plot was at least twice the county average for that year, which was probably due to the correct application of careful agricultural techniques and the small size and more homogeneous soil of the plots. Using the minimum dose recommended by the manufacturer, we measured higher average yields for all wheat varieties, but the difference exceeded 10% only in the case of Mv Nemere, while for the other varieties it ranged between 5-6%, which cannot be considered significant compared to the control.

However, the high average yield was accompanied by poorer quality, with only a few varieties achieving Class II status (according to MSZ EN ISO 27971:2015), even on the treated plots. On the other hand, the treated individuals showed higher values for the quality parameters examined (measured by non-standard methods). The most significant increase was observed in the case of Mv Kondás, where we measured 40% higher protein content, 80% higher gluten content, 137% higher W value, and 45% higher Zeleny index.

In 2022, 21% less wheat was harvested than in 2021, with a national average yield of 4.5 t ha^{-1}, compared to 5.9 t ha^{-1} in the previous year. The purchase price was 83% higher in 2022 (128.000 HUF per tonnes) than in 2021 (72.500 HUF per tonnes). Higher yields achieved with plant conditioners can significantly increase revenue. In our case, the applied dose of 1 L ha^{-1} did not result in a 20-30% increase in yield, which we observed with other soil bacteria preparations (LAPOSI et al. 2020), so it is definitely recommended to use a higher dose, especially in areas prone to drought. In our experiment, we measured a 10% increase in average yield for one species on the treated plots compared to the control, which represents an additional profit of HUF 60.000 in a given year. However, the 5-6% increase measured for the other species only resulted in an additional profit of approximately HUF 32.000, which, considering the price of the product used (HUF 26.000 at a dose of 2 L ha^{-1}), cannot be considered significant. However, it may be reasonable due to further improvements in quality parameters.

Farmers have access to a number of vegetation indices for monitoring cultivated crops and estimating expected yields. The best known and most widely used is the NDVI index, which provides information on chlorophyll content and, indirectly, on the nitrogen supply of the plant, in addition to the structure of the vegetation. However, its value is influenced by a number of environmental factors (atmospheric and soil properties, crop structure) and correlates differently with these physiological processes in different phenological phases (HUANG et al. 2013; SULTANA et al. 2014).

In our previous soil bacterium experiments (KAPRINYÁK et al. 2018., LÁPOSI et al. 2020), we observed that in various arable crops (corn, sunflower, rapeseed, barley), the NDVI index did not show significant differences between the control and treated fields, but several other indices did, which provide information about physiological processes other than chlorophyll content. These include the CRI, ARI, and PRI indices, which refer to the amount and function of protective pigments, the SIPI index, which indicates stress sensitivity, and the PWI and SRWI indices, which refer to water content. In our experiment, at the beginning of ear emergence, we found significant differences between the treated and control plots based on chlorophyll content in three species: Mv Nemere, Mv Kondás, and Mv Pelsodur. Among the vegetation indices, 7 out of 9 parameters showed significant differences in Mv Nemere, and 6 out of 9 parameters showed significant differences in Mv Kondás and Mv Pelsodur, which makes them suitable for early assessment of the effects of treatment. Some of these indices are available from free satellite databases, but they can also be produced using drone-mounted or portable multi- or hyperspectral cameras, which provide information at the field level. In many cases, the differences are not significant due to the high variance of the data, but the crop is more homogeneous on the treated plots, as indicated by the lower variance of the data, and this ultimately results in higher average yields (LÁPOSI et al. 2020). The use of these indices in the earlier stages of the growing season, e.g., before flowering, provides information on the health status of the cultivated crop, allowing appropriate interventions (nutrient replenishment, irrigation, plant protection) to be carried out, thus enabling effective integration into precision farming practices.

References

AGAPIOU A. – HADJIMITSIS D. – ALEAKIS D. (2012): Evaluation of broadband and narrowband vegetation indices for the indentification of archaeological crop marks. Remote Sensing 4(12), 3892–3919. https://doi.org/10.3390/rs4123892

ARREGUI L.M. – LASA B. – LAFARGA A. – IRANETA I. – BAROJA E. – QUEMADA M. (2006): Evaluation of chlorophyll meters as tools for N fertilization in winter wheat under humid Mediterranean conditions. European J. of Agronomy 24(2): 140–148 https://doi.org/10.1016/j.eja.2005.05.005

ASD (2007): FieldSpec 3 User's Manual. ASD Inc., USA.

BÉLTEKI I. (2019): Őszi búza fajtákkal végzett kísérletek a tájnak megfelelő fajták kiválasztására. Doktori (PhD) értekezés. Szent István Egyetem, Gödöllő. https://real-phd.mtak.hu/1582/1/belteki_ildiko_ertekezes_DOI.pdf

CURRAN P.J. – DUNGAN J.L. – GHOLZ D.L. (1990): Exploring the relationship between reflectance red edge and chlorophyll content in slash pine. Tree Physiol. 7: 33–48. https://doi.org/10.1093/treephys/7.1-2-3-4.33

FILELLA I. – SERRANO I. – SERRA J. – PEÑUELAS J. (1995): Evaluating wheat nitrogen status with canopy reflectance indices and discriminant analysis. Crop Sci. 35, 1400–1405. https://doi.org/10.2135/cropsci1995.0011183X003500050023x

GABRIEL J.L. – ZARCO-TEJADA P.J. – LOPEZ-HERRERA P.J. – PEREZ-MARTÍN E. – ALONSO-AYUSO M. – QUEMADA M. (2017): Airborne and ground level sensors for monitoring nitrogen status in a maize crop. Biosystem Engineering 160: 124–133. https://doi.org/10.1016/j.biosystemseng.2017.06.003

GAMON J.A. – SERRANO L. – SURFUS J.S. (1997): The photochemical reflectance index: an optical indicator of photosynthetic radiation use efficiency across species, functional types, and nutrient levels. Oecologia 112, 492–499. https://doi.org/10.1007/s004420050337

GITELSON A.A. – MERZLYAK M.N. (2004): Non-destructive Assessment of Chlorophyll Carotenoid and Anthocyanin Content in Higher Plant Leaves: Principles and Algorithms. Papers in Natural Resources. 263. http://digitalcommons.unl.edu/natrespapers/263

HOLLÓ S. – PETHES J. – AMBRUS A. (2009): A tartós szerves és műtrágyázás hatása a talaj könnyen oldható foszfortartalmára Kompolton, csernozjom barna erdőtalajon. Tartamkísérletek jelentősége a növénytermesztés fejlesztésében. Jubileumi tudományos konferencia. Martonvásár, 2009. október 15. 227–234.

HUANG J. – WANG X. – LI X. – TIAN H. – PAN Z. (2013): Remotely Sensed Rice Yield Prediction Using Multi-Temporal NDVI Data Derived from NOAA's-AVHRR. Plos One, 8(8). https://doi.org/10.1371/journal.pone.0070816

JOLÁNKAI M. – SZABÓ M. (2005): Búza. 183-204. p. In: ANTAL J. (Szerk.): Növénytermesztéstan 1. A növénytermesztéstan alapjai, Gabonafélék. Mezőgazda Kiadó, Budapest. 391 p.

KÁDÁR I., HOLLÓ S. (2006): Műtrágyázás és meszezés hatása a 30 éves kompolti OMTK kísérletben. Agrokémia és Talajtan, 55(2), 433–448. https://files.core.ac.uk/download/pdf/227754317.pdf

KAJDI F. (2011): A búza minősége és annak vizsgálata. Agronapló, 2011/05. https://www.agronaplo.hu/agrofokusz/20140205/a-buza-minosege-es-annak-vizsgalata-33105

KAPRINYÁK T. – LÁPOSI R. – BEKŐ L. – TÓTH SZ. (2018): Effects of combined nutrient supply treatments on some physiological parameters of autumn wheat. Acta Agraris Debreceniensis 241–251. https://doi.org/10.34101/actaagrar/150/1720

KÁTAI J. – SÁNDOR ZS. (2011): Alkalmazott talajtan. Az Agrármérnöki MSc. szak tananyagfejlesztése. TÁMOP-4.1.2-08/1/A-2009-0010 projekt.

KIZILGEÇI F. – CEBELI Z. (2024): Proximal canopy sensing of twenty-two bread wheat genotypes for nutritional quality, yield attributes and grain yield under Mediterranean climate. International Journal of Agriculture Environment and Food Sciences, 8(2), 347–358. https://doi.org/10.31015/jaefs.2024.2.10

KUMMERER K. – HELD M. – PIMENTEL D. (2010): Sustainable use of soils and time. Journal of soil and water conservation. 65(2): 141–149. https://doi.org/10.2489/jswc.65.2.141

LÁPOSI R. – BEKŐ L. – KAPRINYÁK T. – MOLJAK S. – TÓTH SZ. (2020): Evaluation of soil bacteria treatments on some physiological parameters of crops by spectral vegetation indices. Ecocyles 6: 134–145. https://doi.org/10.19040/ecocycles.v6i1.167

MAKÁDI M. (2010): Ásványi és szerves adalékanyagok hatása a nyírségi homoktalajok mikrobiológiai tulajdonságaira. Doktori értekezés, Szent István Egyetem, Környezettudományi Doktori Iskola, 157 p.

MAKÁDI M. – TOMÓCSIK A. – OROSZ V. – LENGYEL J. – BIRÓ B. – MÁRTON Á. (2007): Effects of biogas ferment juice and Phylazonit MC soil bacteria product on green biomass of silage maize and biological activity of the soil (in Hungarian). Agrokemia es Talajtan 56: 367–378. https://doi.org/10.1556/agrokem.56.2007.2.12

MERZLYAK M.N. – GITELSON A.A. – CHIVKUNOVA O.B. – RAKITIN V.Y. (1999): Non-destructive optical detection of pigment changes during leaf senescence and fruit ripening. Physiol Plant. 106: 135–141. https://doi.org/10.1034/j.1399-3054.1999.106119.x

MORAN J.A., MITCHELL A.K., GOODMANSON G., STOCKBURGER K.A. (2000): Differentiation among effects of nitrogen fertilization treatments on conifer seedlings by foliar reflectance: a comparison of methods. Tree physiology 20: 1113–1120. https://doi.org/10.1093/treephys/20.16.1113

PEÑUELAS J. – BARET F. – FILELLA I. (1995): Semi-empirical indices to assess carotenoids/chlorophyll a ratio from leaf spectral reflectance. Photosynthetica 31(2): 221–230. https://www.researchgate.net/publication/229084513

PEÑUELAS J. – FILELLA I. (1998): Visible and near-infrared reflectance techniques for diagnosing plant physiological status. Trend Plant Sci 3: 151–156. https://ui.adsabs.harvard.edu/link_gateway/1998TPS.....3..151P/doi:10.1016/S1360-1385(98)01213-8

PIETRINI F. – IANNELLI M. A. – MASSACCI A. (2002) Anthocyanin accumulation in the illuminated surface of maize leaves enhances protection from photo-inhibitory risks at low temperature, without further limitation to photosynthesis. Plant, Cell and Environment 25: 1251–1259. https://doi.org/10.1046/j.1365-3040.2002.00917.x

POLLHAMER E-NÉ (1981): A búza és a liszt minősége. Mezőgazdasági Kiadó, Budapest. 199 p.

RAJCAN I. – TOLLENAAR M. (1999): Source:sink ratio and leaf senescene in maize: ll. Nitrogen metabolism during grain filling, Field Crops Research 60(3): 255–265. https://doi.org/10.1016/S0378-4290(98)00143-9

RASPER V.F., PICO M.L. – FULCHER R.G. (1986): Alveography in quality assessment of soft white winter wheat cultivars. Cereal Chemistry, 63, 359–400. https://www.cerealsgrains.org/publications/cc/backissues/1986/Documents/chem63_395.pdf

SANKARAN S. – KHOT L.R. – ESPINOZA C.Z. – JAROLMASJED S. – SATHUVALLI V.R. – VANDEMARK G.J. – MIKLAS P.N. – CARTER A.H. – PUMPHREY M.O. – KNOWLES N.R. – PAVEK M.J. (2015): Low-altitude, high-resolution aerial imaging systems for row and field crop phenotyping: a review. European Journal of Agronomy 70: 112–123.

SERRANO L. – USTIN S.L. – ROBERTS D.A. – GAMON J.A. – PEÑUELAS J. (2000): Deriving water content of chaparral vegetation from AVIRIS data. Remote Sens. Environ., 74, 570–581. http://dx.doi.org/10.1016/S0034-4257(00)00147-4

STAMP S.R.H. – BOONE C.C. (1989): Comparison of nondestructive chlorophyll-sensitive photometer and destructive methods of chlorophyll determination. Proceedings of the Florida State Horticultural Society. 101, 333–335.

SUGÁR E. (2014) Martonvásári búza genotípusok növekedésdinamikájának és termésprodukciójának vizsgálata különböző N-tápelem szinteken. PhD értekezés. Szent István Egyetem, Gödöllő. https://real-phd.mtak.hu/1290/1/SUGAR_ESZTER_PHD_DISZERTACIO_DOI.PDF

SULTANA S.R. – ALI A. – AHMAD A. – MUBEEN M. – ZIA-UL-HAQ M. – AHMAD S. – ERCISLI S. – JAAFAR H.Z.E. (2014): Normalized Difference Vegetation Index as a Tool for Wheat Yield Faisalabad, Pakistan. Hindawi Publishing Corporation The Scientific World Journal, Volume 2014, Article ID 725326, 8 pages, https://onlinelibrary.wiley.com/doi/10.1155/2014/725326

SZILÁGYI G. (2013): A vetésváltás és trágyázás hatása az őszi búza SPAD értékeire csernozjom talajon. Agrártudományi Közlemények, 56, 123–126. ISBN: 1587-1282

TÓTH N. (2011): A környezeti tényezők hatása az árpa és a maláta söripari tulajdonságaira, Doktori értekezés, Szent István Egyetem, Gödöllő. https://szie.hu/file/tti/archivum/Toth_Nikolett_ertekezes.pdf

VERAVERBEKE W.S. – DELCOUR J.A. (2002): Wheat protein composition and properties of wheat glutenin in relation to breadmaking functionality. Crit Rev Food Sci Nutr. 42(3): 179–208. https://doi.org/10.1080/10408690290825510

ZARCO-TEJADA, P. J. – USTIN, S. L. (2001): Modeling canopy water content for carbon estimates from MODIS data at land EOS validation sites. International Geoscience and Remote Sensing Symposium, 2001. IGARSS '01, Vol. 1. 342–344. https://doi.org/10.1109/IGARSS.2001.976152

ZARCO-TEJADA, P. J. – USTIN S.L. – WHITING M. L. (2005): Temporal and Spatial Relationships between Within-Field Yield Variability in Cotton and High-Spatial Hyperspectral Remote Sening Imagery. Agronomy Journal, 97(3): 641–653. https://doi.org/10.2134/agronj2003.0257

Website references

Website 1 - https://www.met.hu/ismeret-tar/erdekessegek_tanulmanyok/index.php?id=3261&hir=2022._a_tortenelmi_aszaly_eve_%E2%80%93_az_ev_agrometeorologiai_attekintese Download date: 20/08/2025

Website 2 - https://kormany.hu/hirek/aszalykarok-a-mezogazdasagban Download date: 21/08/2025

Website 3 - https://mikro-vital.hu/mv-supary-2/ Download date: 13/08/2025

Website 4 - https://elitmag.com/vetomag/mv-nemere/ Download date: 08/08/2025

Website 5 - https://elitmag.com/vetomag/mv-nador/ Download date: 08/08/2025

Website 6 - https://elitmag.com/vetomag/mv-menrot/ Download date: 08/08/2025

Website 7 - https://elitmag.com/vetomag/mv-krajcar/ Download date: 08/08/2025

Website 8 - https://elitmag.com/vetomag/mv-kolo/ Download date: 08/08/2025

Website 9 - https://elitmag.com/vetomag/mv-felleg/ Download date: 08/08/2025

Website 10 - https://elitmag.com/vetomag/mv-kondas/ Download date: 08/08/2025

Website 11 - https://elitmag.com/vetomag/mv-pelsodur/ Download date: 08/08/2025

Website 12 - https://www.ksh.hu/s/kiadvanyok/fobb-novenykulturak-termeseredmenyei-2022/fobb-novenykulturak-termeseredmenyei-2022.pdf Download date: 20/08/2025

Website 13 - https://agraragazat.hu/hir/tesztanyujthatosag-vizsgalatok/ Download date: 23/12/2024

Authors

Dr. Réka Láposi, PhD
associate professor, corresponding author
Hungarian University of Agriculture and Life Sciences, Institute of Agronomy
H-3200 Gyöngyös, Mátrai. u. 36. Károly Róbert Campus
laposi.reka@uni-mate.hu

Anna Fruzsina Dudás
BSc. in agricultural engineering
Hungarian University of Agriculture and Life Sciences, Institute of Agronomy
H-3200 Gyöngyös, Mátrai. u. 36. Károly Róbert Campus

Dr. Szilárd Zsolt Tóth, PhD
associate professor
Hungarian University of Agriculture and Life Sciences, Institute of Agronomy
H-3200 Gyöngyös, Mátrai. u. 36. Károly Róbert Campus

Dr. Rita Tury, PhD
assistant professor
Hungarian University of Agriculture and Life Sciences, Institute of Environmental Sciences
H-3200 Gyöngyös, Mátrai. u. 36. Károly Róbert Campus

Dr. Ildikó Bélteki, PhD
assistant professor
Hungarian University of Agriculture and Life Sciences, Institute of Agronomy
H-3200 Gyöngyös, Mátrai. u. 36. Károly Róbert Campus