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Data for the tick faunal studies of Kis-Balaton

Adatok a Kis-Balaton kullancsfaunisztikai vizsgálataihoz

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Abstract: Recently, significant changes have been observed in the distribution patterns of ticks in Europe. Climate change affects the distribution and activity of ticks and also contributes to the emergence of new species, posing a serious health risk to people. The author conducted his studies between June 2023 and April 2024 in the inner areas of Kis-Balaton, starting from the Research House. Ticks were collected using the dragging method in 8 areas. During the 11-month of the survey, the author found 240 specimens of 5 species. *Dermacentor reticulatus* occurred with the highest frequency (78% of the collected individuals), and was found in the areas in every month except January. In addition, *Dermacentor marginatus* (14.5%), *Ixodes ricinus* (5.4%), *Haemaphysalis concinna* (1.6%), and *Haemaphysalis inermis* (0.4%) were found. *Dermacentor* species occurred in all months of the study period, while *I. ricinus* was present in the area in March, April and June. The thermophilous species *H. concinna* was found in the collected sample in June, while the cold-tolerant *H. inermis* was found in the collection in February. The survey results clearly show that ticks, which are responsible for the spread of tick-borne encephalitis, TIBOLA, Lyme disease, tularemia, and other significant diseases, are present in the area, with peak activity in spring and autumn.

***Keywords**: Kis-Balaton; tick; dragging; Dermacentor; climate change*

Összefoglalás: Az utóbbi időben jelentős változások figyelhetők meg a kullancsok elterjedési mintázatában Európában. A klímaváltozás hatással van a kullancsok elterjedésére, aktivitására és hozzájárul új fajok megjelenéséhez is, amelyek komoly egészségügyi kockázatot jelenthetnek a lakosságra nézve. A szerző vizsgálatait 2023 júniusa és 2024 áprilisa között végezte a Kis-Balaton belső területein a Kutatóháztól kiindulva. A kullancsok gyűjtése dragging módszerrel történt 8 területen. A felmérés 11 hónapja alatt 5 faj 240 példányát találta meg a szerző. Legnagyobb gyakorisággal a *Dermacentor reticulatus* fordult elő (a gyűjtött egyedek 78%-a), amely január kivételével minden hónapban megtalálható volt a területeken. Ezen kívül *Dermacentor marginatus (14,5%)*, *Ixodes ricinus (5,4%)*, *Haemaphysalis concinna (1,6%)* és *Haemaphysalis inermis (0,4%)* fajok kerültek elő. A *Dermacentor* fajok a vizsgálati időszak valamennyi hónapjában előfordultak, míg az *I. ricinus* március, április és június hónapban volt jelen a területen. A *H. concinna* melegkedvelő faj, ennek megfelelően júniusban fordult elő a gyűjtött mintában, míg a *H. inermis* hidegkedvelő, a februári gyűjtés során került elő. A felmérés eredményei jól mutatják, hogy a kullancsok, amelyek felelősek többek között a kullancsencephalitis, a TIBOLA, Lyme-kór, tularémia és egyéb jelentős betegségek terjesztéséért, jelen vannak a területen, tavaszi és őszi aktivitási csúccsal.

***Kulcsszavak**: Kis-Balaton; kullancs; dragging; Dermacentor; klímaváltozás*

1. Introduction

The study of the distribution and species composition of ticks (Ixodidae) is essential not only from an ecological perspective but also because of their public health importance. Tick distribution is influenced not only by the movement of host organisms (e.g., wildlife, migratory birds, dogs, cats, humans) but also by climate change, which increasingly facilitates the appearance of tick species not previously established in Hungary. With the growing likelihood of the introduction and emergence of novel pathogens, the risk of human infections also increases. Therefore, regular field surveillance and tick collection aimed at monitoring the occurrence and prevalence of native species responsible for transmitting human and (other) mammal pathogens, as well as the early detection of newly expanding species, is of outstanding preventive importance.

Due to changing climatic conditions, the distribution range of ticks in Europe is beginning to shift compared to previous patterns, and they are now detected even at higher altitudes (Cunze et al., 2022). In addition, global warming may have a significant impact on the occurrence and frequency of vector-borne diseases (Gray et al., 2009). Given the changing environmental conditions, the regular monitoring of tick species across different habitats is indispensable.

In Central and Western Europe, *Ixodes ricinus* (Linnaeus, 1758) is one of the most important and most frequently occurring tick species (Gray et al., 2024; Tóth et al., 2023). It is the principal vector of Lyme borreliosis (Lakos, 2012; Burn et al., 2023) and a transmitter of viruses, bacteria, and protozoa (Burn et al., 2023). The causative agent of Lyme disease is the *Borrelia burgdorferi* sensu lato species complex (Földvári and Rigó, 2009). In addition, *I. ricinus* is also primarily responsible for the transmission of tick-borne encephalitis (Zubriková et al., 2020).

In Central Europe, and in Hungary as well, the second most widespread tick species is *Dermacentor reticulatus* (Fabricius, 1794) (Rubel et al., 2014). It frequently occurs in cooler regions. While it is considered a characteristic species of floodplain and marshy habitats (Földvári and Farkas, 2005), in Hungary it has also established populations in drier grasslands (Hornok and Farkas, 2009). One of the most important human diseases transmitted by *D. reticulatus* is TIBOLA (tick-borne lymphadenopathy), which is most often caused by *Rickettsia slovaca* and *Rickettsia raoultii* (Barthel et al., 2025). The species also plays a role as a secondary vector in the transmission of the tick-borne encephalitis virus (Sidorenko et al., 2021). Furthermore, *D. reticulatus* is the primary vector of *Babesia canis*, the causative agent of canine babesiosis (Koczwarska et al., 2023).

Dermacentor marginatus (Sulzer, 1776) is typically associated with steppe habitats and drier meadows. In Hungary, it occurs primarily in the Transdanubian region, with the highest prevalence in Somogy, Zala, and Vas counties (Földvári and Farkas, 2005). The transmission of Q fever is most commonly linked to this species; however, the pathogen may also enter the human body via sheep as intermediate hosts or through the consumption of unpasteurized raw cow's milk (Kimmig et al., 2004).

Haemaphysalis concinna (Koch, 1844) plays an important role in the transmission of tick-borne encephalitis and tularemia (caused by *Francisella tularensis*), and it also serves as a vector for numerous pathogens of both human and veterinary relevance (Rubel et al., 2018). It is an endemic species in Europe. In Hungary, it is the third most widespread tick species after *I. ricinus* and *D. reticulatus* (Rubel et al., 2014).

2. Materials and Methods

During my research, I investigated the occurrence and frequency of various tick species in the Kis-Balaton area between June 2023 and April 2024. Sampling sites were selected within the

inner areas, some of which are frequently visited by tourists during guided tours, while the remaining areas are primarily accessed by professional staff. Tick occurrence was examined at eight locations: 1. Research House, 2. Bank of the Gyöngyös Creek, 3. Meadow, 4. Diás Island, 5. Almás Island Lookout, 6. Ingói Marshes, 7. "Mulch area", and 8. Airport corner (Figure 1). Collections were conducted during the morning or early afternoon depending on weather conditions.

Field surveys were performed using the dragging method. A 1 m² light-colored textile towel attached to a pole was dragged over the vegetation at each sampling site for a standardized duration of 8 minutes. The towel was checked every 3–4 meters within the sampling area. Ticks easily clung to the loops of the towel fabric and were collected using tweezers. Specimens were stored in 1.5 ml Eppendorf tubes containing 70% ethanol. Species identification was carried out using a stereomicroscope, referencing Babos Sándor's faunistic guide (1965) and Hillyard's (1996) identification keys.

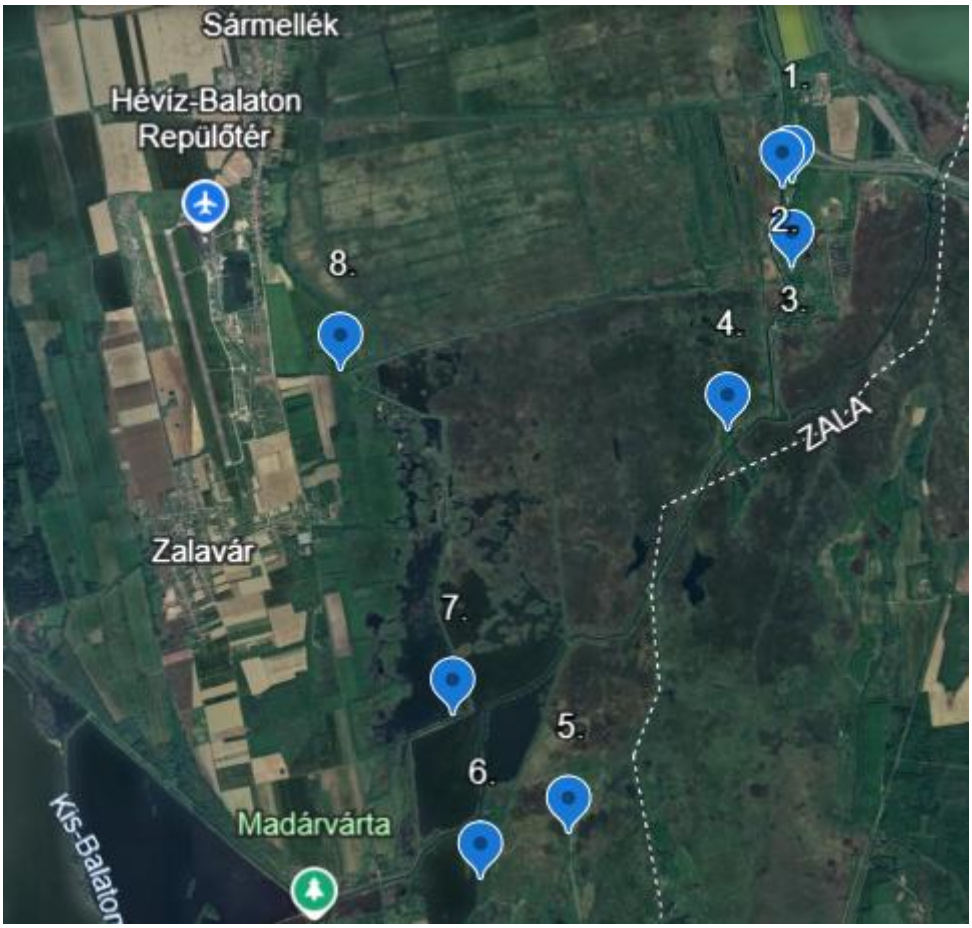

Figure 1 *Simpling locations: 1. Research house, 2.Bank of the Gyöngyös creek, 3.Meadow, 4.Diás Island, 5.Almás Island Lookout, 6. Ingói Marshes, 7. "Mulch area", 8. Airport corner (Source of locations: Google Earth web)*

3. Results

During the study period, a total of 240 ticks were collected, belonging to the genera *Dermacentor*, *Ixodes*, and *Haemaphysalis*.

Research House: This site represents a grassland–forest ecotone. A total of 61 ticks were collected here, of which 74% were *D. reticulatus* (28 males, 17 females). No specimens were collected from January to March or during the hot summer months. The majority of individuals were collected in September (6 females, 2 males) and October (7 males, 5 females). Nine *D. marginatus* specimens (4 females, 5 males) were collected between March and April. For *I. ricinus*, two specimens were collected in June and two in March, while three *H. concinna* were collected in June (1 larva, 1 adult male, 1 adult female).

Bank of the Gyöngyös Creek: Dense grass cover provided suitable microhabitats for ticks. Only *Dermacentor* species were collected here: 38 *D. reticulatus* and 17 *D. marginatus*. All ticks were adults. Of the *D. reticulatus*, 27 were males and 11 females; for *D. marginatus*, 11 were females and 6 males. Peak abundance occurred in October, November, and February. No ticks were collected in July, December, or January.

Meadow: Characterized by grasslands with floodplain forest vegetation. A total of 31 ticks were collected, 87% of which were *D. reticulatus* (19 females, 9 males). Peak abundance for this species was observed in October and April, with the lowest, a single individual, in June. The species was absent during summer and winter months. Two *D. marginatus* males were collected in July, one female *I. ricinus* in June, and one male *H. concinna* in June.

Diás Island: A frequently visited area with surrounding floodplain forest providing shaded habitats. Periodic water coverage occurs during rainy weather, creating unfavorable conditions for ticks. A total of 29 ticks were collected, 72% of which were *D. reticulatus* (15 females, 6 males). Three female *D. marginatus*, three female *I. ricinus* and one male, and one female *H. concinna* were also collected.

Almás Island Lookout: Frequently visited by tourists, with notable wildlife activity contributing to tick distribution. Only *Dermacentor* species were collected: 23 *D. reticulatus* (17 females, 6 males) and one *D. marginatus*. Most *D. reticulatus* were collected in April (7 specimens), with additional activity in September (5) and October (4), as well as February (5).

Ingói Marshes: Sampling occurred on the grassy area between the embankment and the roadside forest strip. Low numbers of three species were collected: *D. reticulatus* (4 females, 3 males), *D. marginatus* (1 male), and *Haemaphysalis inermis* (1 male). Peak abundance of *D. reticulatus* was recorded in September and April (3 individuals each), with one individual in February. The *D. marginatus* male was collected in January, and the *H. inermis* male in February.

"Mulch Area": Also located between embankment and forest strip. Mostly *D. reticulatus* were collected (11 individuals: 7 females, 4 males). Peak activity was observed in April (6 specimens), with 2 collected in September and 3 in a mild February period. One *D. marginatus* was collected in October, and one *I. ricinus* in June.

Airport corner: Characterized by mixed grass and woody vegetation, with high wildlife activity. Only *Dermacentor* species were found: 17 *D. reticulatus* (10 females, 7 males) and one *D. marginatus*. Specimens were only collected in September and April.

Considering overall species occurrence, four species were recorded at the Research House and Kis-Diás Island (*D. reticulatus*, *D. marginatus*, *I. ricinus*, *H. concinna*). Only *Dermacentor* species were found at the Gyöngyös Creek, Almás Island, and Airport Corner, whereas *I. ricinus* also occurred at the Meadow, Mulch Area, and Ingói Marshes. *H. inermis* was only detected at Ingói Marshes.

Monthly occurrence data (Tables 1 and 2) show two main activity peaks. In 2023, *D.* reticulatus dominated in September and October, with high abundance continuing in November. *D. marginatus* showed higher occurrence in October and April. The year 2023 was among the warmest in recent Hungarian history, contributing to high tick numbers during the autumn period. *I. ricinus* was observed in low numbers in June, March, and April. *H. concinna* was only recorded in June at the Research House and Kis-Diás Island.

Table 1 Occurrence of tick species between June and November 2023 (number of individuals) in the Kis-Balaton region

Species/Collection date	June	July	Aug.	Sept.	Oct.	Nov.
Dermacentor reticulatus	2		7	28	36	17
Dermacentor marginatus	2	2	1	1	10	3
Ixodes ricinus	5					
Haemaphysalis concinna	4					
Haemaphysalis inermis						

Table 2 Occurrence of tick species between December and April 2024 (number of individuals) in the Kis-Balaton region

Species/Collection date	Dec.	Jan.	Feb.	Mar.	Apr.
Dermacentor reticulatus	2		21	10	64
Dermacentor marginatus		1	5	2	8
Ixodes ricinus				7	1
Haemaphysalis concinna					
Haemaphysalis inermis			1		

During the surveys, 97.5% of the collected ticks were in the adult stage. Only seven nymphs (3 *I. ricinus*, 4 *D. reticulatus*) and one larva (*H. concinna*) were found alongside the adults. The species composition was 78% *D. reticulatus*, 14.5% *D. marginatus*, 5.4% *I. ricinus*, 1.6% *H. concinna*, and 0.4% *H. inermis*.

The high tick abundance in the autumn months was due to the unusually warm weather. September 2023 temperatures were 3.5°C higher than in previous years, and October was also milder than usual. Daily mean temperatures in 2023 deviated significantly from the multi-year average, resulting in the warmest autumn months since 1901 (Internet1). The winter months of 2023/2024, following the mild autumn, were the warmest recorded since 1901. February was particularly mild, showing spring-like temperatures (Internet2). These conditions also affected tick activity: in February, *D. reticulatus* was present in high numbers at the study sites. *D. marginatus* was recorded in January and February. During the March and April collections, a significant number of *D. reticulatus* (n=64) indicated their active period.

4. Discussion

The collections from June 2023 to April 2024 demonstrate that environmental conditions in the Kis-Balaton region are suitable for the permanent presence of ticks. Their occurrence varies

among sites, as it is influenced by specific habitat preferences, the presence of hosts, and fluctuating temperatures. Milder winters and a long, warm autumn extend the active period of ticks, increasing the potential for pathogen transmission.

During my surveys, *Dermacentor* species were present in all months in the inner areas of Kis-Balaton, demonstrating both the high adaptability of these species and increasingly favorable temperature conditions. Milder winters and the absence of snow facilitate the proliferation of tick populations. Their primary hosts in the region, red deer and wild boar are abundant, contribute to the wider distribution of these species within Kis-Balaton. *Ixodes ricinus*, *Haemaphysalis concinna* and *H. inermis*, in contrast to *Dermacentor* species, prefer cooler, shaded habitats. *I. ricinus* specimens were observed in March, April, and June at half of the sampling sites. Their activity peaks in May–June, followed by a second autumn peak. The four *H. concinna* specimens collected in June indicate that this species favors warmer conditions, whereas the *H. inermis* collected in February is cold-adapted.

Among the tick species recorded in Kis-Balaton, *D. reticulatus* and *I. ricinus* are of particular public health significance. *I. ricinus* is the main vector of the tick-borne encephalitis virus, while *D. reticulatus* primarily transmits TIBOLA and, to a lesser extent, also contributes to the transmission of tick-borne encephalitis virus to humans. Additionally, *D. reticulatus* is a significant vector of *Babesia canis* in dogs. All species studied play an important role in transmitting pathogens to humans, making their monitoring and knowledge of occurrence essential for disease prevention and control.

The highly diverse fauna of Kis-Balaton ensures the presence of suitable hosts for ticks, allowing all developmental stages to feed and develop. Kis-Balaton is part of the Natura 2000 network, designating it as a protected area, especially for birds. The avifauna is particularly rich, especially during migration periods, highlighting the importance of monitoring the local tick population. Global warming may facilitate the introduction of tick species by migratory birds, which pose potential threats to humans. In recent years, *Hyalomma* species have appeared in Hungary, likely transported by migratory birds. *Hyalomma marginatum* (Koch, 1844) and *Hyalomma rufipes* (Koch, 1844) are among the most important vectors of Crimean-Congo hemorrhagic fever. Ticks are active from spring to autumn and can survive the winter in Hungary following molting. There is no treatment for the viruses carried by these ticks, and human infection can be fatal (Internet3). Observing the spread of these non-native ticks is crucial, especially given their distinct hunting behaviour, as they actively pursue hosts, unlike local species which wait on vegetation.

The unique bird fauna of Kis-Balaton warrants attention not only for conservation purposes but also for public health, due to the potential presence of dangerous tick species. Mapping the distribution of potentially lethal ticks is crucial for preventive measures. Faunistic surveys are indispensable for this purpose.

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In Vitro Biocontrol Potential of Endophytic Methylobacterium sp. Against Plant Pests Pseudomonas savastanoi and Botrytis sp.

Az endofita Methylobacterium sp. in vitro biokontroll-potenciálja a Pseudomonas savastanoi és a Botrytis sp. növényi kórokozók ellen

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Abstract: Fungi and pathogenic bacteria cause numerous plant diseases that significantly affect crop productivity. The use of biological control agents represents an environmentally friendly alternative to chemical pesticides. The present study aimed to evaluate the *in vitro* antagonistic effects of *Methylobacterium sp.* against *Pseudomonas savastanoi* and *Botrytis sp.*, two major phytopathogens affecting olive (*Olea europaea L.*) and faba bean (*Vicia faba L.*), respectively.The bacterial strain *Methylobacterium sp.*, isolated from nodules of *Retama monosperma*, was tested for its antibacterial activity against *P. savastanoi* using the direct method of Fleming et al. (1975) and the indirect method of Barefoot and Klaenhammer (1983). The antifungal potential against *Botrytis sp.* was assessed by the direct confrontation technique on Mueller-Hinton agar medium. The results revealed that no inhibition was observed with the direct method, whereas the indirect method showed a clear inhibitory zone of approximately 5 mm against *P. savastanoi*, indicating that the inhibitory metabolites are mainly intracellular. The confrontation test demonstrated a significant reduction in *Botrytis sp.* mycelial growth; with an inhibition rate exceeding 38%. These findings highlight the potential of *Methylobacterium sp.* as a promising biological control agent against bacterial and fungal phytopathogens. Further studies under *in vivo* conditions are required to confirm its efficacy and identify the active metabolites involved in the antagonistic activity.

***Keywords**: Methylobacterium sp; Pseudomonas savastanoi; Botrytis sp; olive; biological control*

Összefoglalás: A gombák és a patogén baktériumok számos növénybetegséget okoznak, amelyek jelentősen befolyásolják a terméshozamot. A biológiai növényvédő szerek alkalmazása környezetbarát alternatívát jelent a kémiai növényvédő szerekhez képest. A jelen tanulmány célja az volt, hogy értékelje a *Methylobacterium* sp. in vitro antagonisztikus hatásait a *Pseudomonas savastanoi* és a *Botrytis* sp. ellen, amelyek az olíva (*Olea europaea* L.) és a bokorbab (*Vicia faba* L.) két fő növénypatogénjei. A *Methylobacterium* sp. bakteriális törzset, amelyet a *Retama monosperma* gümőiből izoláltak, antibakteriális aktivitás szempontjából teszteltük a *P. savastanoi* ellen a Fleming és munkatársai (1975) által kidolgozott közvetlen módszerrel, valamint a Barefoot és Klaenhammer (1983) által alkalmazott közvetett módszerrel. A *Botrytis* sp. elleni gombaellenes potenciált a közvetlen konfrontációs technikával értékeltük Mueller-Hinton agaron. Az eredmények azt mutatták, hogy a közvetlen módszerrel nem figyeltünk meg

gátlást, míg a közvetett módszer kb. 5 mm-es egyértelmű gátló zónát mutatott a *P. savastanoi* ellen, ami arra utal, hogy a gátló hatású metabolitok főként intracellulárisak. A konfrontációs teszt jelentős csökkenést mutatott a *Botrytis* sp. micélium növekedésében, a gátlási arány meghaladta a 38%-ot. Ezek az eredmények kiemelik a *Methylobacterium* sp. potenciálját, mint ígéretes biológiai növényvédelmi ágens a bakteriális és gombás fitopatogének ellen. További in vivo körülmények között végzett vizsgálatokra van szükség a hatékonyság megerősítésére és az antagonista aktivitásban szerepet játszó aktív metabolitok azonosítására.

***Kulcsszavak**: Methylobacterium sp; Pseudomonas savastanoi; Botrytis sp; olíva; biológiai védelem*

1. Introduction

Pathogenic microorganisms affecting plant health pose a major and ongoing threat to food production and ecosystem stability worldwide. (de Weger et al., 1995; Gai and Wang, 2024). The olive tree (*Olea europaea* L.) and the faba bean (*Vicia faba* L.) are cultivated species susceptible to attacks by phytopathogenic agents such as *Pseudomonas savastanoi* and *Botrytis* sp., respectively. Their rapid and insidious development leads each year to the destruction of hundreds of olive trees and dozens of hectares of faba beans. These pathogens cause significant economic losses, and the chemical methods used to control them can have harmful side effects on the environment and health. Among the alternatives to chemical control, the use of biological protection is an effective solution that helps combat plant pathogens while reducing the use of chemical products. Biological control of plant pathogens is more environmentally friendly than chemical control (Nautiyal, 2000). Among the antagonists present in soils with balanced microflora, the genus *Methylobacterium* sp., PGPR (Plant growth-promoting rhizobacteria) holds an important place due to its beneficial interactions with plants (Han, 2024).In this study, we investigated the in vitro antagonistic effect of *Methylobacterium* sp. against *Pseudomonas savastanoi* and *Botrytis* sp., in order to assess its potential as a biocontrol agent. The study focused on the isolation, pre-identification of the pathogens, and the evaluation of the antibacterial and antifungal activity of *Methylobacterium* sp. using various methods.

2. Materials and Methods

2.1. Microbial and plant material

The microbial material consists of strains of *Methylobacterium* sp. isolated from *Retama monosperma* nodules. The strain was provided by the LP2VM laboratory. The studied strain was cultured on Mueller-Hinton (MH) (Guiraud, 2003) (Fig.1).

Figure 1 *Macroscopic appearance of Methylobacterium sp. colonies obtained after several subcultures on solid MH medium.*

Pseudomonas savastanoi strains were isolated from infected olive (*Olea europaea* L.) twigs, while *Botrytis* sp. was isolated from faba bean (*Vicia faba* L.) leaves exhibiting characteristic brown spots.

2.2. Isolation and purification

Fragments of infected olive tree branches were disinfected with 95% alcohol, rinsed, and then macerated in distilled water or phosphate-buffered saline (PBS) (EPPO, n.d.) for 30 minutes. The resulting macerate was used for inoculation on Levure Peptone Glucose Agar medium (LPGA) (Guiraud, 2003) and Mueller-Hinton (MH) agar, incubated at 26°C for 24–72 hours. The isolated colonies were purified by successive subculturing on MH medium and stored at 4°C. For *Botrytis* sp., fragments of infected leaves were disinfected in a 2% sodium hypochlorite solution for 3–5 minutes, rinsed three times with sterile distilled water, and then placed on Potato Dextrose Agar (PDA) (EPPO, n.d.) medium. The plates were incubated at 25°C for 5–7 days until mycelium appeared, and then subcultured to obtain pure cultures. All experimental procedures were conducted in the bacteriology laboratory of the Regional Plant Protection Service (SRPV) of Oran, Algeria, in accordance with standard protocol of the European and Mediterranean Plant Protection Organization (EPPO, n.d.).

2.3. Study of antibacterial activity

The antibacterial activity of *Methylobacterium* sp. against *Pseudomonas savastanoi* was evaluated using both direct and indirect approaches. In the direct method (Fleming et al., 1975), colonies of the two strains were placed in direct contact on Mueller-Hinton (MH) agar and incubated at 28°C for 3 days, after which inhibition zones were observed. In the indirect method (Barefoot and Klaenhammer, 1983), the supernatant from a *Methylobacterium* sp. culture or its pure suspension was placed into wells prepared in MH agar seeded with the indicator strain, and the plates were incubated at 28°C for 3 days to assess inhibition. All antibacterial assays were performed in three independent replicates, and representative results are presented.

2.4. Study of antifungal activity

The antifungal activity of *Methylobacterium* sp. against *Botrytis* sp. was evaluated using the direct confrontation method. A fungal disc was placed on a Petri dish containing MH medium, which supports the growth of the bacterial antagonist, at a distance of 3 cm from a bacterial streak. A control containing only the fungus was prepared. After incubation at 26°C for 10 days,

mycelial growth was measured and the inhibition percentage was calculated as described by (Wang et al., 2002).

$$(\%)\ \text{inhibition} = (R_{control} - R_{test}) / R_{control} \times 100$$

- $R_{control}$: maximum radial distance of fungal growth.
- R_{test}: radial distance along a line toward the antagonist.
- Inhibition was considered significant for values ≥20%.

All antifungal assays were conducted in three independent replicates, and representative results are shown.

3. Results

3.1. Antibacterial activity against *P. savastanoi*

Tests conducted using the direct method showed no visible inhibition zones around the *Methylobacterium* sp. colonies (Figure 2). The rapid growth of *P. savastanoi* (24 h) appeared to outpace that of *Methylobacterium sp*. (72 h), preventing effective inhibitory interaction.

In contrast, the indirect method revealed significant antibacterial activity: the pure suspension of *Methylobacterium* sp. produced a clear inhibition zone of about 5 mm in diameter (Figure 3). This result suggests that the metabolites responsible for the inhibition are intracellular rather than extracellular (Mina et al., 2020). Similar results were observed in the other two replicates.

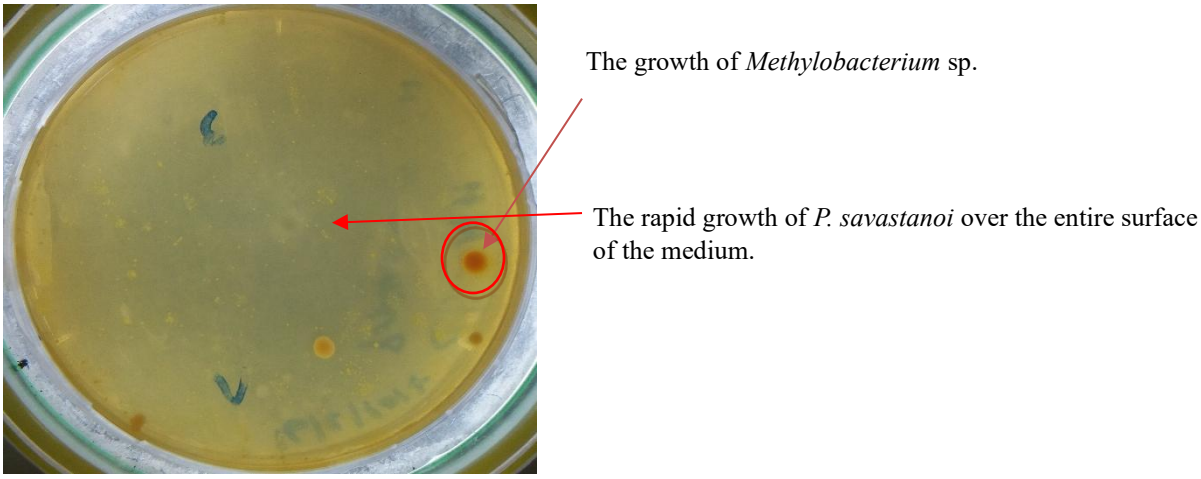

Figure 2 *Results obtained by the spot method according to Fleming et al. (1975).*

Figure 3 *Antibacterial activity of Methylobacterium sp. against P. savastanoi using the Barefoot and Kaenhammer (1983) method, adapted.*

3.2. Antifungal activity against *Botrytis* sp.

The assessment of the antagonistic effect of *Methylobacterium* sp. against *Botrytis* sp. through direct confrontation showed a clear inhibition of mycelial growth (Figure 4). The calculated average inhibition percentage exceeded 38%, indicating a significant antagonistic interaction. Although the inhibition percentage reported here corresponds to one representative replicate, similar trends were observed in other repetitions (data not shown). The comparison with the control (Figure 5) confirms that the growth of the fungus is significantly reduced in the presence of *Methylobacterium* sp., demonstrating its potential to limit the development of *Botrytis* sp. Comparable inhibition was observed in the other replicates.

A *B*

A. ***Figure 4*** *Representation of the results of the direct confrontation on the Botrytis sp. Strain.*

B. ***Figure 5*** *The control only contains the phytopathogenic fungus after 6 days.*

4. Discussion

Our results are in line with those of Poorniammal et al. (2009) and Egamberdieva et al. (2015), and align with more recent findings (Ehinmitan et al., 2025; Photolo et al., 2020),who also observed an antifungal effect of *Methylobacterium* strains against various pathogens, suggesting that this activity could be related to the production of secondary metabolites or competition for nutrients. Based on our results, we can suggest that *Methylobacterium* sp. could exhibit an eco-friendly approach by modulating certain experimental parameters such as pH, incubation time, temperature, and the concentration of the inhibitory strain. These factors strongly influence the production and diffusion of antibacterial and antifungal metabolites, as reported by Ehinmitan et al. (2025) and Egamberdieva et al. (2015). Furthermore, co-inoculation with *Trichoderma* sp. could enhance the effectiveness of biocontrol. According to (Mahmoudi, 2012; Risoli et al., 2022), Trichoderma species exhibit strong antagonistic effects against *Botrytis* sp. Similarly, Schierling et al. (2024) demonstrated that Trichoderma spp. and beneficial bacteria (*Kosakonia* sp.) can act complementarily within integrated management strategies against B. cinerea, even when combined with reduced fungicide use. These findings suggest that combining *Methylobacterium* sp. with *Trichoderma* sp. could represent a promising, eco-friendly biocontrol approach.

5. Conclusion

The study highlighted the in vitro antagonistic potential of *Methylobacterium* sp. against two major phytopathogenic agents, *Pseudomonas savastanoi* and *Botrytis* sp. The results show significant antibacterial activity against *P. savastanoi* using the indirect method and an inhibition of mycelial growth of *Botrytis* sp. greater than 38%.These observations confirm that *Methylobacterium* sp. could serve as a promising biological control agent, potentially complementing or partially replacing chemical treatments. Further studies, particularly in vivo, are needed to confirm the efficacy of this strain, characterize the metabolites responsible for the inhibitory activity, and optimize application conditions in a sustainable agricultural context.

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The first period of a successful local sport in the ranks of Georgikon

Egy sikeres helyi sportág első időszaka a Georgikon berkeiben

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Abstract: At Georgikon, which has more than 225 years of tradition, in addition to teaching a wide spectrum of disciplines, the institution's task is also to provide students with an appropriate level of physical preparation. In recent years, the local appearance of badminton, an increasingly popular sport, has been closely intertwined with the university. The development of this sport started with the rental of gyms by a few keen badminton enthusiasts in the Keszthely area, and then found its home at Georgikon. It eventually became an official national sports association and currently serves both the town and the university. Badminton is a sport that originated in India and then officially spread from England in the middle of the 19th century. This sport is on the program of the Summer Olympic Games since 1992. In Hungary you can play badminton on indoor courts in around 80 locations, and the number of official clubs is currently around 60. Half of the domestic badminton venues are located in and around Budapest. Badminton is currently played in 5 settlements in Zala County. The Keszthely Badminton Association has been officially registered since 2011. Thanks to a small enthusiastic group, it was previously possible to play badminton in Keszthely, and since the beginning of the 2000s, those who like the game have rented various city gyms for training. Since 2010, the gym of Georgikon has been used as the training venue for the sport. The association currently has around 50 active members, mostly hobby players and a smaller part competitors. Among the players of different ages, in addition to the larger town membership, university students, university employees and their family members are also represented. Badminton is one of the 20 official sports associations in Keszthely, which has gained recognition in the area and is still very popular today.

Keywords*: badminton, Keszthely, Georgikon, health preservation, university*

Összefoglalás: A több, mint 225 éves hagyománnyal bíró Georgikonon a széles spektrumú tudományágak oktatása mellett a hallgatók megfelelő szintű fizikai felkészítése is az intézmény feladata. Az utóbbi években egyre népszerűbb tollaslabda sportág helyi megjelenése szorosan összefonódik az egyetemmel. A sportág fejlődése a néhány Keszthely környéki lelkes tollaslabdát kedvelő sportember tornatermek bérléseivel indult, majd a Georgikonon talált otthonra. Végül hivatalos országos egyesületté vált, s jelenleg is szolgálja a várost és az egyetemet egyaránt. A tollaslabdázás egy Indiából eredő, majd hivatalos szabályokkal a 19. század közepi Angliából világszerte elterjedő sportág. A Badminton elnevezés egy angliai települést jelöl. A

hazánkban is egyre népszerűbb mozgásforma a nyári olimpiai játékok programjában 1992-től szerepel. A beltéri tollaslabda játék mintegy 80 helyszínen űzhető Magyarországon, a hivatalos klubok száma pedig 60 körüli jelenleg. Budapesten és Pest vármegyében található a hazai tollaslabdázási helyszínek fele. Zala vármegyében jelenleg 5 településen tollaslabdáznak. A Keszthelyi Tollaslabda Egyesület hivatalosan bejegyzett formában a 2011. évtől működik. Egy kisebb lelkes társaság révén korábban is volt már tollaslabdázási lehetőség Keszthelyen, a 2000-es évek elejétől az edzésekhez különböző városi tornatermeket béreltek a játékot kedvelők. 2010-től a Georgikon tornaterme szolgál a sportág edzéseinek helyszínéül. A nagyobb részben hobby játékosokból, kisebb részben versenyzőkből álló aktív tagok száma jelenleg 50 fő körüli az egyesületben. A különböző életkorú játékosok között a nagyobb városi tagság mellett az egyetemi hallgatók, egyetemi dolgozók és családtagjaik is képviseltetik magukat. A tollaslabda a 20 keszthelyi hivatalos sportegyesület egyike, mely elismertséget vívott ki magának a környéken, s mely ma is igen népszerű. Ebben szerepet játszik az a tény, hogy viszonylag kis fizikai felkészültség és technikai tudás megléte esetén is igen szórakoztató játék. Az elmúlt évtized során több mint 200 fő már legalább kipróbálta a sportágat a városban, a Georgikon tornacsarnokában, hivatalos beltéri körülmények között. Ez a szám Keszthely mai lakosságának több mint egy százalékát teszi ki.

Kulcsszavak: *tollaslabda, Keszthely, Georgikon, egészségmegőrzés, egyetem*

1. Introduction

The healt-preserving effect of sport cannot be questioned. Numerous international and domestic researches have previously proven that physical activity plays a key role in maintaining our health (e.g. Ács, Borsos and Rétsági 2011; Lee et al. 2011; Stephens 1988; Caspersen et al. 1985). Movement improves our condition, thus our healt, and can help us live a longer, quality life. The range of sports is very wide. Everyone can find the right form of exercise for them. This study deals with the sport of badminton and its situation in Hungary, more specifically in Keszthely. The sport of badminton has undergone rapid development both internationally and domestically in the past half century.

No matter how you look at it, the perception of badminton in schools, leisure sports, or association sports is positive. The reason for this is probably that badminton is a very fun game despite the relatively low level of physical preparation and technical knowledge. Its increasing popularity worldwide led, amond other things, to badminton being included in the program of the Olympic Games from 1992 (Lemke, Meseck, 1996). Today, badminton is one of the most popular sports with the most followers on Earth. According to some Internet sourches, with 950 million followers, it ranks 6th in these statistics (Internet 1), which is mainly due to Asian followers. It is estimated that more than 200 million people play this sport worldwide today.

2. Materials and Methods

The method of the study is basically document analysis. It is primaraly based on what kind of growth and change occurred in Keszthely with the appearance of the sport of badminton in the area, and how it became popular recently. In addition to the rather narrow domestic and international written badminton literature, there are some internet sources that provide help in this regard. In Keszthely, the statistical data series, annual reports and reports of the association (KETE) help to outline a more accurate picture of the situation. We tried to present the local development of the sport with diagrams and figures, during which the increase in the number of athletes, the appearance of the younger generation at training sessions, the local interest in

summer children's camps, and the regional interest in the amateur adult competitions organized by the association were primaraly in focus. Data extracted from reports and other literature were analyzed using descriptive statistical methods and processed using Microsoft Office 2013 excel.

3. Results and Discussion

Badminton become an officially recognized sport in Hungary in 1966 (Fodor et al. 1983, Rázsó 2010). During the emergence of the sport of Badminton in Hungary and its rapid development over the past 50 years, more and more people practise this form of exercise in our country. Thanks to coaching training, the number of professionals working in the sport of Badminton has increased. With the further training of physical education teachers and the equipping of schools with badminton equipment, the sport in our country has undergone a great development in terms of the education of the younger generation. The Hungarian Badminton Association organizes the competitions, training camps, and organizes the briefly outlined system. From elementary school to the end of high school (6 age groups), among others, amateurs and competitors can train at the Student Olympics, and competitions are even organized for university students. The number of official clubs is constantly increasing (over 60, Internet 2), and today this game can be played at more than 80 locations in Hungary.

Contrary to popular belief – that this sport is mostly played in beaches and gardens, and the goal is to keep the shuttlecock in the air for as long as possible – badminton is a typical indoor sport. The outdoor conditions – wind, sunshine, rain, etc. – they reduce the enjoyment value of the game, but it can be played outdoors as a hobby. The basic goal of the game of badminton is to force the opponent to make a mistake. Those sports halls are suitable for the official sport of badminton, in which it is possible to create several courts, and in which in addition to the appropriate court dimensions (6.1 meter width, 13.40 meter length; Fodor et al. 1983), the necessary interior height is also available. The sport can be played excellently even with a hall height of 6-7 meters, however, 9 meters in more serious competitions, and 12 meters for Olympic and world competitions is the minimum requirement.

Of course, when training young people for sports and healthy physical exercise, the smaller available track sizes and facilities are also sufficient at the beginning. In the case of badminton rackets, there is a wide selection, from metal beginner rackets to graphite and titanium professional rackets. Similarly in the case of shuttlecocks, there is also an abundant supply on the market, from various plastic shuttlecocks to the official competition shuttlecocks consisting of 16 goose feathers. In terms of sportswear, badminton has no special requirements, and in terms of sports shoes, there is also a large selection available, from the simplest sneakers to the most professional indoor shoes, depending on the skill level.

The start of indoor badminton in Keszthely can be dated to the turn of the millenium. In the beginning, a few local sports-loving hobby players (including Anita Kalamár, Csilla Korponay, Olivér Farkas, Tibor Szép, Gyula Buzás, Attila Buzás, János Márvány, István Lénárt, Ferenc Ángyán, Zsolt Rózsakerti, Péter Koncz, Tamás Tóth, Ákos Pintér) rented the gym of a primary school in Keszthely and than a secondary school of Hévíz for a few years on a weekly basis for the game. The difficulty was that you couldn't paint lines anywhere. Thus, every time the lines of the track had to be prepared at the beginning of the sessions with glue or chalk. It was a big step forward when, Ákos Pintér joined the university as a sport instructor, it was finally possible to paint 3 badminton courts in the sports hall of Georgikon, Keszthely (the first team in 2012, Figure 1).

Photo 1 *The first badminton team in Keszthely*

Source: own photo (2012)

From then on, regular, official badminton could be played in this sportshall twice a week in the town. Shortly thereafter, at the and of 2011, 15 people – including several of those listed above – founded the Keszthely Badminton Association (KETE, Founding Document, 2011), which was accepted by the Hungarian Badmintos Association among its national official associations. The general assembly elected Ákos Pintér as the first president, and Olivér Farkas and Gábor Mayer as board members (Minutes, 2011). Since then, badminton trainings have been regular in the town on Thursday and Sunday evenings, for 13 years now – with the exception of the nearly 3-month summer holidays. Currently, the composition of the presidency is roughly the same (Gábor Mayer was replaced by Endre Nagy; Minutes, 2023).

After the renovation of the university sports surface in 2015, badminton training is now held on 4 badminton courts (Figure 2). The number of people attending the initial training of 8-10 people quickly increased in the association. Since badminton is played in very few places in Zala County (besides Keszthely, in Zalaegerszeg, Bagod and 2 years ago in Gyenesdiás), the news of this sport quickly spread. Children, university students and adults alike signed up to play badminton. Members have 2 training sessions each time. Beginners are followed by advanced training. The sessions are managed by qualified coaches (3 people, Ákos Pintér, Olivér Farkas and Miklós Fazekas). The fourth, former coach, Barbara Dancsa, moved from the town in 2023.

Photo 2 *Badminton training in the gym of Georgikon*

Source: own photo (2024)

The association rents the sports hall from the university (formerly University of Pannonia, now Hungarian University of Agricultural and Life Sciences) on an ongoing basis. Basically, the members keep the association going, in addition, financial support for smooth operation comes from tenders and a few years ago from the Keszthely Municipality as well. In addition to the town members visiting the training, Georgikon's teachers, employees, their family members and university students are also represented in the association. From the beginning of the 2010s, the sport of badminton was also included in university education at Georgikon. From then on, students could take up badminton as part of compulsory and optional physical education subjects and play the sport. The relationship between the badminton association and Georgikon became closer as a result. In addition to the hobby nature, some students from Georgikon also participated in national university badminton championships.

Since the beginning, more than 200 people have tried playing badminton in the town, which represents more than 1% of the population of Keszthely. The current number of active members is 55 (Presidential written annual report, 2024; Table 1), almost half of which are children and youth players. The data also show that the majority of players attending the association's training sessions are under 18 and over 35 (Table 2).

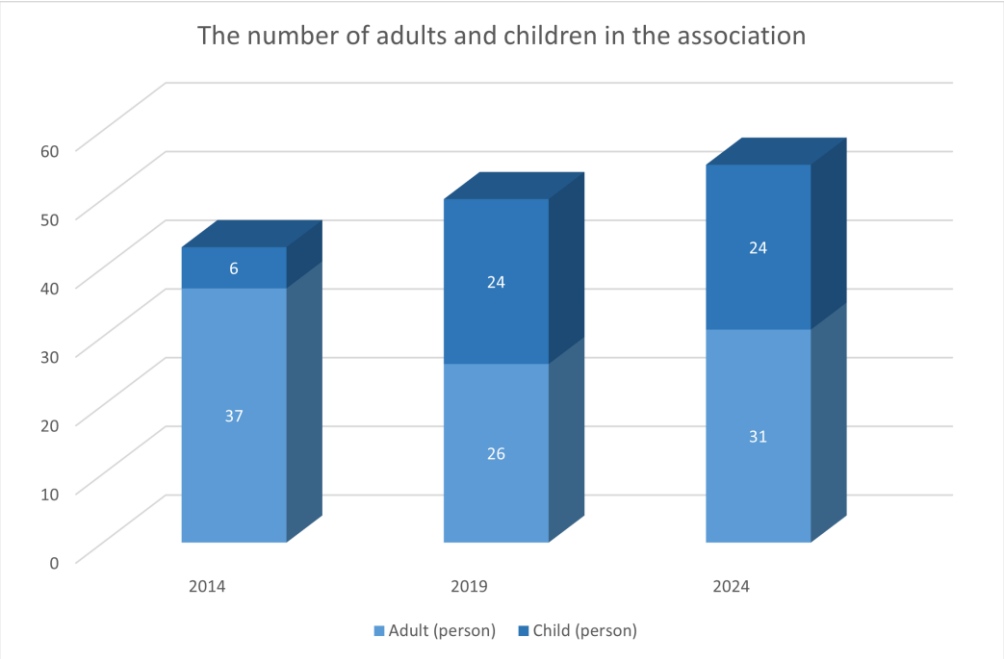

Figure 1 *The number of active members in the association*

Source: editing from own data (Presidential written annual reports)

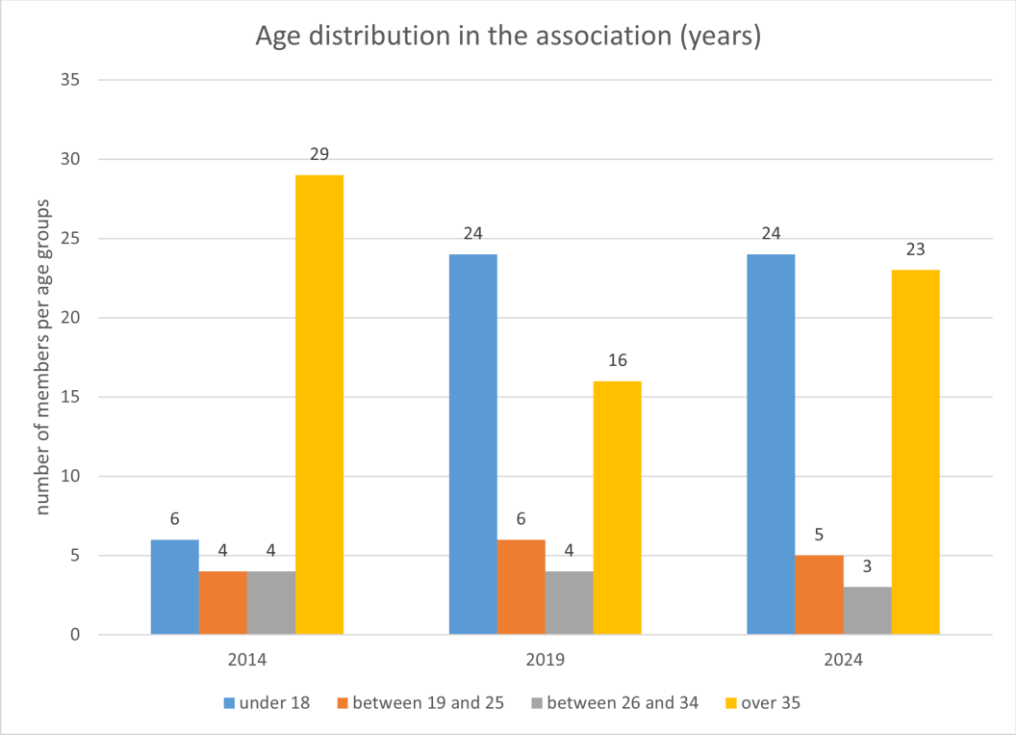

Figure 2 *Age distribution in the association*

Source: editing from own data (Presidential written annual reports)

The primary goal of the association is to preserve health. Therefore, although KETE is a hobby club, young children have been succesfully competing in student badminton competitions for years. Several of them have already appeared in national finals (national 5th places are the best

so far, thanks to Kamilla Kutasy and Ákos Kovács-Markó). Several of the adults regularly participate in amateur regional competitions in the country, where they have already achieved numerous podium positions. We have so far won 2 gold, 3 silver and 4 bronze medals in senior national badminton championships – categories starting at the age of 35 (thanks to Anita Kalamár, Judit Szabó Meszlényiné, Gábor Mayer, Olivér Farkas and Ákos Pintér). Every year, KETE organizes a regional amateur adult badminton competition in Keszthely (Table 3), as well as occasional county Student Olympic rounds for children. It is clear from the data that there is a serious interest in these competitions in the region. In addition to the local competitors, players mostly come to Keszthely from Tapolca, Szombathely, Győr, Pápa, Bagod, Segesd, Zamárdi, Kaposvár and Pécs (Presidential written annual reports, 2011-2024).

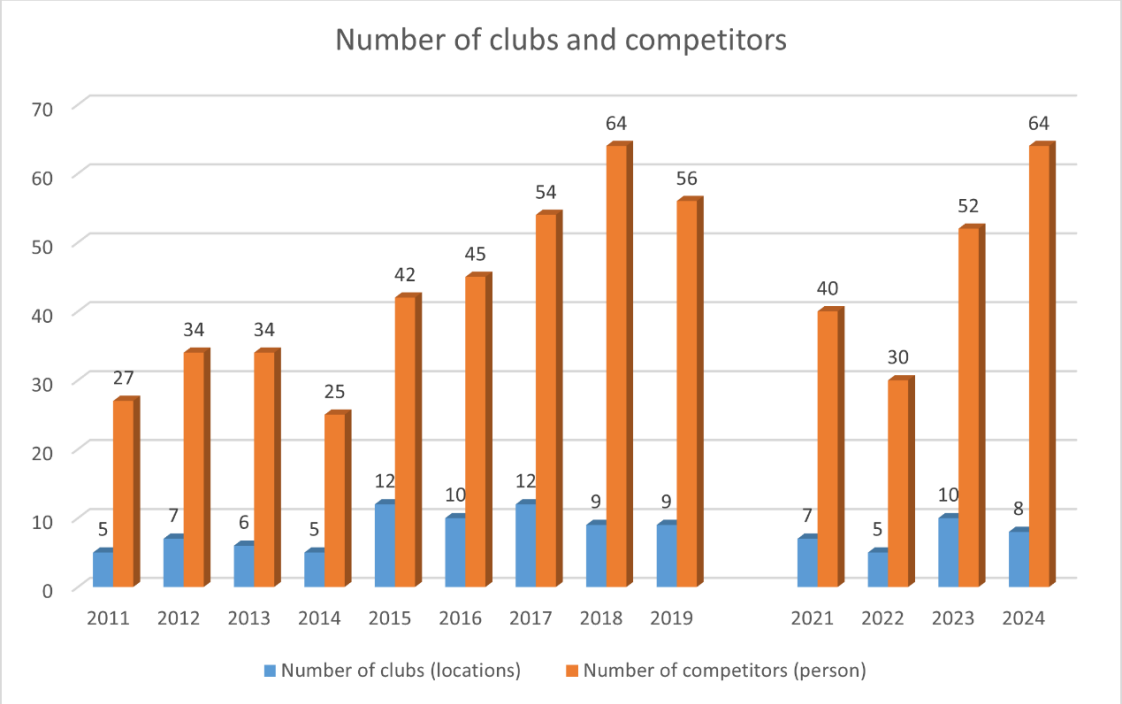

Figure 3 *Regional adult badminton competitions in Keszthely*

Source: editing from own data (Presidential written annual reports)

In the summer, from the beginning, the association holds 1-2 one-week summer children's camps per year (Table 4), the effect of which is clearly visible in the recent increase in the number of young association players. In such cases, in addition to the local coaches, a guest instructor (in the past Imre Pánovics, and in recent years the badminton coach Henriett Illés Takácsné from Segesd) helps with the children's camp. In addition to Keszthely, children also come to the camps from smaller settlements in the area, where, in addition to getting to know the sport, they can also go to the beach and participate in other joint team-building programs.

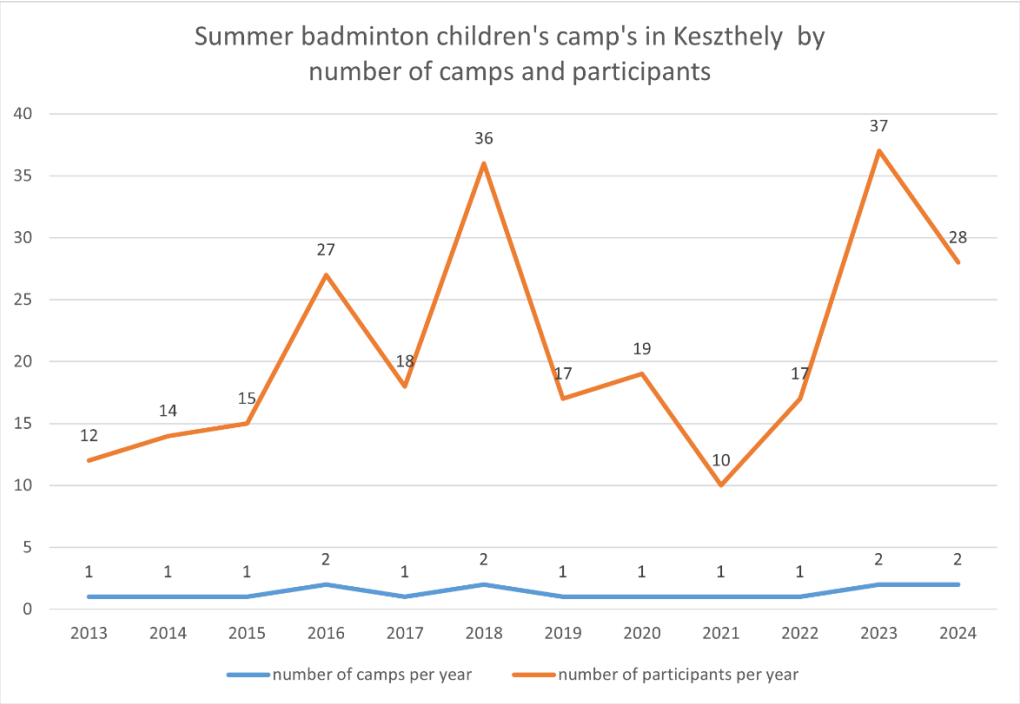

Figure 4 *Summer badminton children's camps in Keszthely*

Source: editing from own data (Presidential written annual reports)

KETE has already appeared on several forums in and around Keszthely, presenting the sport of badminton. The association regularly participates in fall sports programs organized several times in the town, where you can get to know the sport at demonstration training sessions. This is also necessary, since in this way the supply is ensured, because a smaller dropout can be observed in the older generations. It was an excellent local advertisement for badminton that the Hungarian male participant of the Tokyo 2020 Summer Olympics (because of Covid, it was in 2021), Gergely Krausz, had already visited the association and played with the members. On two occasions in the summer, we were invited to Révfülöp (Summer of Balaton, national TV show), during which we were able to promote our beloved sport and Keszthely, more widely. It is gratifying that KETE is recognized in the town and in the region, and the opinion of the association is already sought in sports-related questions and discussions. In the future, the aim of the association is primarily to pass on the love of movement through this sport, and to train and compete the most skillful players as far as possible (Figure 3).

Photo 3 *The bigger half of the current badminton team in Keszthely*

Source: own photo (2024)

Thanks to the now almost a decade and a half of badminton in Keszthely, regular games started once a week in the neighboring Gyenesdiás settlement a few years ago, where with the construction of the new school gym it became possible to play badminton as well. Since then the official badminton association (GYETE) was also established in the settlement. An excellent relationship has developed between the two clubs, and thanks to the georgraphical location, many people visit the training sessions of both settlements.

4. Conclusions

The relationship between Georgikon and the Keszthely Badminton Association goes back a decade and a half, providing its members with the opportunity to maintain their health through the sport of badminton. In addition to town members, several university students, workers, former workers and people connected with Georgikon also attend the association's training sessions. The staff of the campus sports center also participate in the management of the association and in the teaching of badminton as coaches. Badminton is now one of the few sports in Keszthely that is closely connected to the Georgikon, and thus contributes to enhancing the reputation of the university. Hopefully, in the future, even more university citizens will play sports, either in the association or elsewhere, folllowing the words of the Roman poet Juvenalis: „a sound mind in a sound body".

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Investigation of Leaf Surface Development in Strawberry (*Fragaria × ananassa*) under Differential Water Supply Conditions

Szamóca (Fragaria x ananassa) levélfelület-alakulásának vizsgálata eltérő vízellátás mellett

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Abstract: Strawberry (*Fragaria × ananassa*) is undoubtedly one of the most popular berry crops both in Hungary and worldwide. It can be cultivated using several production methods, most commonly under open-field conditions. In open-field cultivation, water supply represents a critical factor, particularly in the context of climate change. The increasing unpredictability of precipitation threatens yield stability. In our experiment, the responses of three strawberry cultivars (Senga S, Honeoye and Kortes) were examined to determine how their leaf surface area and yield were affected by varying water supply levels. Four irrigation regimes were established: optimal irrigation, and 75%, 50% and 40% of the optimal irrigation volume. Leaf surface area exhibited a sensitive response to water deficit; in all cultivars, decreasing irrigation volumes resulted in a reduction of leaf surface area. Yield assessments indicated that even a 25% reduction in water supply caused a drastic yield decline, ranging from 56.1% to 70.6%. Overall, the results demonstrate that adequate water availability is essential for successful strawberry production and for achieving optimal yield levels in the cultivars included in this study.

Keywords*: water supply; strawberry; horticulture; leaf area*

Összefoglalás: A szamóca (*Fragaria x ananassa*) kétségtelenül hazánk és a világ egyik legnépszerűbb bogyós gyümölcse. Termesztésére több mód áll rendelkezésre, gyakran szabadföldi körülmények között történik. Szabadföldi termesztési mód esetében fontos kérdés a vízellátás, elsősorban a klímaváltozás miatt is. A csapadékosság kiszámíthatatlansága veszélyezteti a termésbiztonságot. Kísérletünkben azt vizsgáltuk, hogy 3 különböző szamóca fajta (Senga S, Honeoye, valamint Kortes) levélfelülete és termésmennyisége hogyan változik a különböző vízellátás hatására. Négy vízellátási szint került beállításra: optimális öntözés, valamint az optimális öntözővíz 75, 50 és 40%-a. A levélfelület érzékenyen reagált a vízmegvonásra, az öntözővíz mennyiségének csökkenésével csökkent minden fajta esetében a levélfelület is. A termés mennyiségének vizsgálata során már a 25%-os vízmegvonás is drasztikus, 56,1–70,6%-os ter-

méscsökkenés volt megfigyelhető. Összességében megállapítható, hogy a sikeres szamóca termesztéshez és az optimális termésmennyiség eléréséhez optimális vízellátottsági körülmények szükségesek a vizsgálatba vont szamócafajták esetében.

***Kulcsszavak**: vízellátás; szamóca; kertészet; levélfelület*

1. Introduction

Due to its shallow root system, strawberry is highly sensitive to soil moisture content (Krüger et al., 1999). Determining the optimal water requirement of strawberry has become a popular and increasingly relevant topic. Identifying cultivars capable of coping with new environmental challenges is of particular importance. For instance, both Klamkowski and Treder (2008) and Bordonaba et al. (2010) examined the effects of water stress on different cultivars and were able to detect significant differences among them. Insufficient irrigation or inadequate water supply results in a reduction in fruit quantity, individual berry weight, and overall yield (Adak et al., 2018). Although nutrient availability also influences fruit production, ensuring adequate fertilization generally represents a less challenging task. At the same time, the effects of irrigation and fertilization on soil nitrate content and the broader environment have attracted increasing scientific attention (Li et al., 2025).

In open-field strawberry production, the most critical months are May, June, and September (Tóth, 1997), as these periods include flowering, fruit set, and the differentiation of next year's flower buds. Optimal yields are achieved when soil pore space is filled to 70–80% capacity (Mohácsy et al., 1965). Previous studies have shown that when irrigation volumes corresponded to 80% of the soil's maximum field capacity, strawberries exhibited vigorous vegetative growth and strong photosynthetic activity (Du et al., 2024). Reasonable and adequately applied irrigation can promote photosynthesis, thereby improving final yields under open-field conditions (Zhang et al., 2018). Conversely, suboptimal irrigation may, to some extent, enhance water-use efficiency in strawberry (Liu et al., 2019). However, when water availability drops below a critical threshold, abscisic acid levels may increase in plant tissues, ultimately reducing yield and fruit quality (Liu et al., 2019).

The aim of our experiment was to investigate three strawberry cultivars widely grown in Hungary—Sonata S, Honeoye and Kortes. We examined how leaf surface area and yield responded to different irrigation levels. Four treatments were applied: optimal irrigation, and water deficit corresponding to 75%, 50%, and 40% of the optimal irrigation volume.

2. Materials and Methods

The experiment was established on 4 April 2023 in the greenhouse of the Department of Agronomy, Institute of Crop Production Sciences, located at Building E of the Hungarian University of Agriculture and Life Sciences, Institute of Agronomy, Georgikon Campus. Three strawberry cultivars (Senga S, Honeoye and Kortes) were compared under four different irrigation regimes. One group received no water stress, while the remaining treatments were subjected to varying levels of water deficit. For each irrigation level and cultivar, three replicates were used, with each replicate planted individually in a plastic pot (30 cm diameter). A peat-based substrate suitable for strawberry cultivation was used as the growing medium, and the soil surface was covered with mulch to reduce evaporative water loss. During the first month, irrigation was applied once per week, based on the amount of water lost through evaporation over the prece-

ding seven-day period. Irrigation was applied from above using a drip irrigation system (Figure 1). To prevent water loss, saucers were placed beneath the pots, ensuring that the supplied water remained available to the plants. Nutrient supply was provided biweekly to ensure that only the effects of water deficit were reflected in the plant traits. During fertilization, each plant received 30 mL of Plantafol 20.20.20 nutrient solution mixed with the irrigation water. Following the establishment of the seedlings, water supply treatments were initiated on 8 May 2023. The plants were divided into four groups: the first received the optimal irrigation volume, while the second, third and fourth groups received 75%, 50% and 40% of the optimal volume, respectively. Leaf surface area was measured weekly using an LI-3000C leaf area meter (Figure 1).

Figure 1 *Leaf area measurement using an LI-3000C device and the installed drip irrigation system.*

3. Results and Discussion

Figure 2 shows the leaf surface area of the three strawberry cultivars (Senga S, Honeoye and Kortes) under four different irrigation treatments. It is clearly visible that the largest leaf areas were recorded under optimal water supply, regardless of cultivar. As irrigation volumes decreased, leaf surface area also declined, with the lowest values observed at 40% of the optimal irrigation level (ranging between 24.9 and 37.3 cm² depending on the cultivar).

Even a 25% reduction in irrigation resulted in a significant decrease in leaf surface area: by 47.5% in Senga S ($p = 0.0276$), by 29.7% in Honeoye ($p = 0.0450$) and by 44% in Kortes ($p = 0.0396$). Overall, irrigation at 40% of the optimal volume reduced leaf surface area by 70.8–79.2% compared to the optimal treatment ($p = 0.0037$–0.0085), depending on the cultivar.

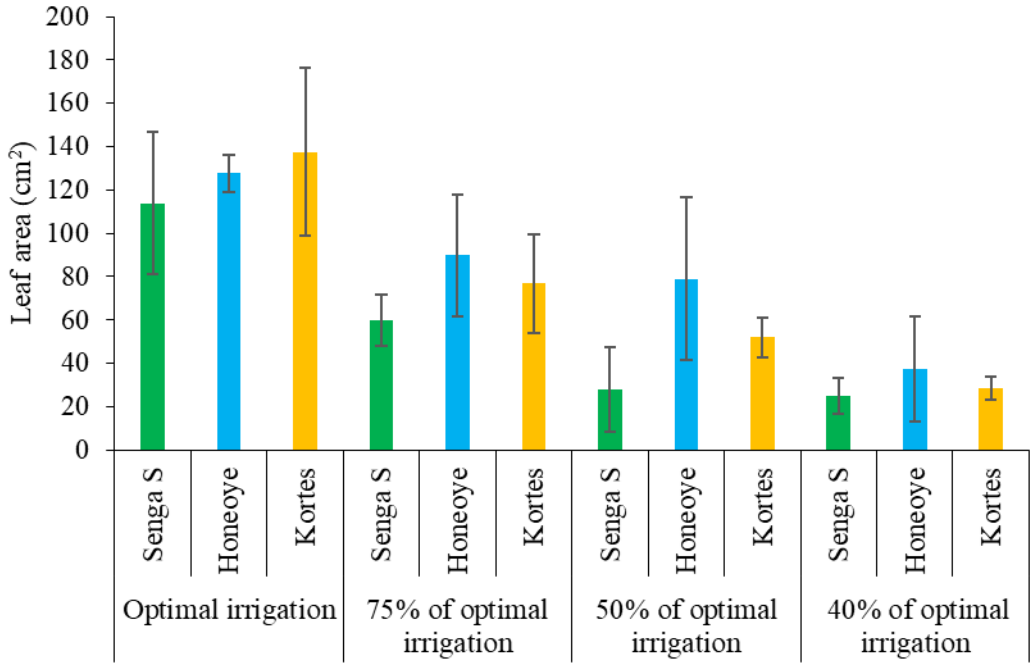

Figure 2 *Leaf surface area of three strawberry cultivars (Senga S, Honeoye and Kortes) under four irrigation treatments (optimal irrigation and 75%, 50% and 40% of the optimal volume)*

The cultivars exhibited differential responses to water deficit. In this experiment, Senga S proved to be the most sensitive to irrigation levels: water reduction relative to the optimal treatment decreased leaf surface area by 47.3–78.1% ($p = 0.0453–0.0103$). Honeoye was the least sensitive cultivar, with leaf surface area reduced by 29.7–70.8% under water deficit ($p = 0.0090–0.0036$). Thus, beyond the effect of irrigation, clear differences among cultivars were also detectable.

Leaf surface area also influenced yield. Figure 3 presents the yield of the three strawberry cultivars (Senga S, Honeoye and Kortes) under different irrigation regimes (optimal irrigation, and 75%, 50% and 40% of the optimal irrigation volume).

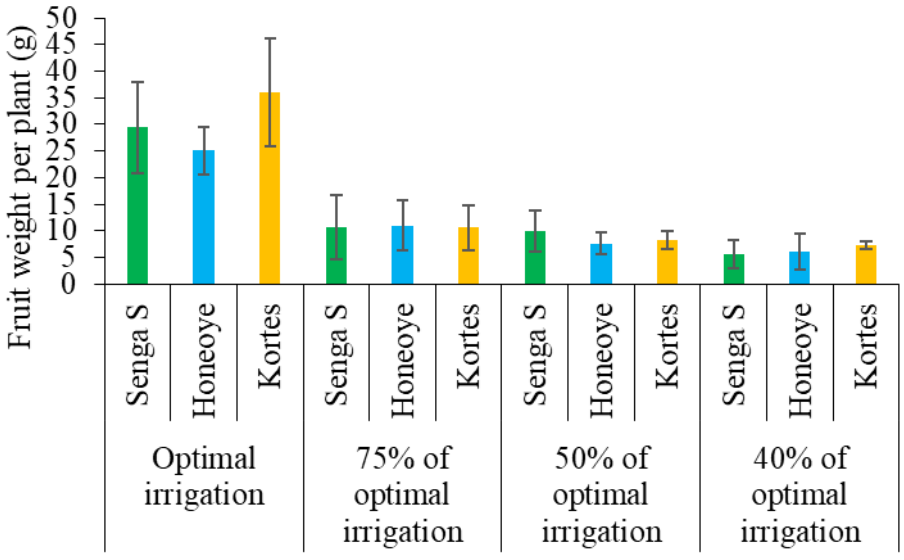

Figure 3 *Fruit yield of three strawberry cultivars (Senga S, Honeoye and Kortes) under four irrigation treatments (optimal irrigation and 75%, 50% and 40% of the optimal volume)*

The highest yield was obtained under optimal irrigation in all three strawberry cultivars examined. Reducing the irrigation volume had a substantial impact on yield, regardless of cultivar. Even a 25% reduction relative to the optimal irrigation level resulted in a drastic yield decline, with fruit weight decreasing by 56.1–70.6% depending on the cultivar ($p = 0.0369–0.0161$). Compared with the 75% irrigation treatment, the 50% water deficit caused a 7.6–31.1% reduction in yield; however, this decrease was statistically significant only in the Honeoye cultivar ($p = 0.0308$). Although lower irrigation intensities affected fruit weight, the differences were not statistically significant.

The assessment of drought tolerance in strawberry cultivars is a relatively well-studied topic. In Poland, Klamkowski and Treder (2008) conducted experiments on the cultivars Elsanta, Elkat and Salut. Similar to our study, frigo plants were planted in a peat-based substrate. In their trial, the Elkat cultivar proved to be the least tolerant to drought. Klamkowski et al. (2015) examined the long-term effects of water stress in three strawberry cultivars, again including Elsanta, alongside Grandrosa and Honeoye. Their study compared a control group with a group subjected to water deficit. The authors found that among the cultivars tested, Elsanta performed the best, while Honeoye showed inferior performance in several parameters. For example, Honeoye exhibited lower photosynthetic activity, the smallest leaf surface area among the cultivars and the least developed root system. Although yield decreased markedly in all cultivars, Honeoye again produced the lowest yields, whereas Elsanta showed the best overall performance.

4. Conclusions

Several publications in the literature address the water supply of strawberry. The results of the present study clearly demonstrate that although the trend associated with water deficit is evident, the magnitude of the response may vary considerably among cultivars. Leaf surface area is related to yield, yet this relationship has been examined less frequently in previous studies. Furthermore, investigations conducted on widely cultivated commercial cultivars remain relatively scarce and therefore fill an important knowledge gap. Our findings may contribute to supporting practical decision-making in cultivar selection for growers.

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Effects of Biostimulants on Leaf Surface Area in Strawberry (*Fragaria* × *ananassa* Duch.)

Biostimulátorok hatása a szamóca (Fragaria × ananassa Duch.) levélfelületére

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Abstract: Biostimulants are already widely used in agriculture and horticulture; however, controlled and well-designed experiments that allow direct comparison of individual products remain limited in the case of strawberry. The aim of our study was to draw attention to the beneficial effects of biostimulants not only in major agricultural crops but also in strawberry production. By examining the effects of the biostimulants included in the experiment (FoliQ AscoVigor, RhizoMagic, Amalgerol and Tytanit) and by publishing scientifically validated data, we intend to support practitioners, as the results may provide guidance for both commercial strawberry growers and home gardeners regarding the expected effects of the tested biostimulants. The experiment was conducted during the spring–summer period of 2023 using three popular strawberry cultivars (Senga Sengana, Korona and Sonata) at the Georgikon Campus of the Hungarian University of Agriculture and Life Sciences in Keszthely. Our results showed that, compared with the untreated control (which received irrigation water only), all treatments resulted in higher leaf surface area values. A dynamic increase in leaf development was also observed in the treated groups. Biostimulant application further enhanced leaf surface area in strawberry, although the magnitude of this increase varied depending on the product applied.

Keywords*: biostimulant; strawberry; horticulture; leaf area*

Összefoglalás: A biostimulátorokat már széles körben alkalmazzák a mezőgazdaságban, illetve a kertészetekben, de a szabályozott, jól beállított kísérletek, amelyek az egyes készítmények összehasonlíthatóságát biztosítanák, igen szűk körűek szamóca esetében. Kutatásunkban szeretnénk felhívni a figyelmet a biostimulátorok jótékony hatásaira, nemcsak a mezőgazdasági kultúrákban, hanem a szamócatermesztésben is. Továbbá a kísérletbe bevont biostimulátorok (FoliQ AscoVigor, RhizoMagic, Amalgerol, Tytanit) hatásának feltérképezésével és a tudományos adatok közzétételével, segítenénk a gyakorlati szakemberek munkáját, mivel a kísérlet eredményei alapján útmutatást nyújthatunk mind a szamócatermesztőknek és a házikertben szamócával foglalkozóknak, az alkalmazott biostimulátorok hatásairól. A kísérletet 3 népszerű sza-

móca fajta bevonásával végeztük (Senga Sengana, Korona, Sonata) 2023 tavaszi-nyári időszakában, a Magyar Agrár- és Élettudományi Egyetem Georigkon Campusán, Keszthelyen. Eredményeink azt mutatták, hogy a kezeletlen kontrollhoz képest (amely csak öntözővizet kapott) minden kezelésben nagyobb levélfelületet értékeket mértünk. A kezelt csoportoknál dinamikus levélfejlődést is megfigyeltünk. A biostimulátoros kezelések hatására a szamócák levélfelülete tovább nőtt, azonban a növekedés mértéke eltérő volt az különböző szerek kijuttatásától függően.

***Kulcsszavak**: biostimulátor; szamóca; kertészet; levélfelület*

1. Introduction

Strawberry (*Fragaria × ananassa* Duch.) is a highly preferred early-season fruit due to its characteristic aroma, bright red colour and juicy texture (Trejo-Téllez & Gómez-Merino, 2014). Its popularity among consumers is primarily attributed to its flavour (Civille & Oftedal, 2012). It is mostly consumed fresh (Trejo-Téllez & Gómez-Merino, 2014), although the processing industry also utilises considerable quantities for juice and jam production.

Strawberry plants possess trifoliate compound leaves (Poling, 2016). The primary factors influencing the yield potential of strawberry cultivars are genetically and physiologically determined (Tagliavini et al., 2005). Fruit quality, on the other hand, cannot always be favourably regulated by external factors such as nutrient supply (Guinto, 2016). Under adequate nutrient and water availability, the inherent yield potential of cultivars can be more fully expressed under given environmental conditions (Lieten & Misotten, 1992). The effectiveness of nutrients depends on how individual elements influence the plant's biochemical and physiological processes (Lieten & Misotten, 1992). Nutrient and water requirements of berry crops are similar, and continuous fertilisation and irrigation are necessary throughout the entire growing season (Horinka, 2010). Nitrogen (N) is essential for plant growth, is a component of all living cells and forms part of all amino acids and chlorophyll molecules (Lieten & Misotten, 1992). Strawberry requires a relatively balanced nitrogen supply (Horinka, 2010); both deficiency and excessive amounts may adversely affect plant development and yield potential (Papp, 2004).

Strawberry is among the crops that require substantial amounts of potassium to achieve optimal yield and fruit quality (Kaya et al., 2003; Khayyat et al., 2009; Ebrahimi et al., 2012). Similar to many horticultural species (Nagy et al., 2008), strawberry is sensitive to chloride (Papp, 1999); therefore, only chloride-free potassium fertilisers can be applied (Papp, 1997; Papp, 1999; Papp, 2004). The phosphorus requirement of strawberry decreases at the onset of fruit ripening, but increases significantly toward the end of the ripening period (Horinka, 2010).

Strawberry leaves are capable of utilising water and water-soluble substances. The absorbed nutrients move through the intercellular spaces to reach their sites of utilisation (Kádár, 2008). Foliar fertilisation is not commonly applied in strawberry plantations; nutrients are typically sprayed onto the leaves only when deficiency symptoms appear (Papp, 2004). According to Horinka (2010), foliar applications not only alleviate nutrient deficiencies but also enhance the resistance of plants that already possess an adequate nutrient supply.

The primary difference between biostimulants and foliar fertilisers is that the effects of biostimulants are not determined by their nutrient content, whereas the efficacy of foliar fertilisers derives from the mineral elements they contain (N, P, K) (Czinege, 2014). Globally, there is no legal or regulatory definition for plant biostimulants. The substances classified under this term are not precisely categorised or listed; however, scientists, regulators and stakeholders acknowledge several main categories (du Jardin, 2015).

In our experiment, the effects of biostimulants were examined on strawberry cultivars commonly used in commercial production. Four biostimulants (FoliQ AscoVigor, RhizoMagic, Amalgerol and Tytanit) and three strawberry cultivars (Senga Sengana, Sonata and Korona) were included in the study. The primary aim of the investigation was to assess how leaf surface area responded to the different biostimulant treatments in the cultivars tested.

2. Materials and Methods

The experiment was conducted in the greenhouse of the Department of Agronomy, Institute of Agronomy, at the Georgikon Campus of the Hungarian University of Agriculture and Life Sciences in Keszthely. Three strawberry cultivars commonly used in commercial production and home gardening—Senga Sengana, Korona and Sonata—were included in the study. The plants were grown in 30 cm diameter plastic pots filled with a peat-based substrate. To prevent desiccation, the surface of the growing medium was covered with wood mulch. Planting took place on 14 May 2023. Subsequently, six treatments were established in the experiment:

1. Control treatment: In this treatment, the strawberry plants received irrigation water only, therefore they could rely solely on the nutrients available in the growing medium. The abbreviation used for this treatment is: C.
2. Plantafol 20.20.20 (Valagro®): This product contains macro- and microelements in EDTA-chelated form and can be applied as a foliar fertiliser, either alone or in combination with other plant protection agents. According to the manufacturer's recommendation, the advised application rate in fruit crops is 2–3.5 kg/ha, applied every 15–20 days from the onset of vegetative growth until the fruit enlargement stage. The abbreviation used for this treatment is: PLF.
3. FoliQ AscoVigor® (Agrii Polska Sp.): This product contains an extract of *Ascophyllum nodosum* seaweed and is additionally rich in macro- and micronutrients, including nitrogen, potassium oxide, boron, manganese and zinc. According to the manufacturer's recommendation, the foliar fertiliser should be applied twice during a single growing season in strawberry plantations. The first application should be carried out after the onset of vegetative growth (before flowering), and the second from bud break until fruit set. The abbreviation used for this treatment is: FQA.
4. RhizoMagic™ (FMC-AGRO Hungary Kft.): This product is frequently used in conventional agricultural production against biotic and abiotic stress factors. The presence of nitrogen, potassium, phosphorus and micronutrients ensures adequate nutrient availability for the plant. The seaweed extract and amino acids contribute to rapid nutrient uptake due to their biostimulant effects. The abbreviation used for this treatment is: RM.
5. TYTANIT® (INTERMAG): The product contains a titanium compound (Ti) in a plant-available form: 0.8% titanium, corresponding to 8.5 g/L (0.8 m/m%) titanium sulfate. According to the manufacturer's recommendation, foliar application should be performed 2–4 times at a rate of 0.2–0.4 L/ha. The abbreviation used for this treatment is: TY.
6. Amalgerol® (Hechenbichler GmbH): The exact composition of the product is not disclosed by the manufacturer to prevent counterfeiting. According to its authorisation document, this plant conditioner contains seaweed extract, plant essential and mineral oils, paraffin oil distillate and herbal extracts. Based on the manufacturer's recommendation, it should be applied every 10–14 days from before flowering until the onset of fruit colouring. The abbreviation used for this treatment is: AM.

In addition to the biostimulant treatments, all plants received a baseline fertilisation with Plantafol 20.20.20. Each treatment was applied with three replicates for each cultivar. Leaf surface area was measured at the stage of maximum leaf expansion on 22 June 2023 using an LI-3000C leaf area meter (LI-COR Environmental GmbH).

3. Results and Discussion

Clear differences were observed between the biostimulant-treated and untreated groups, demonstrating the positive effects of the biostimulants on leaf surface area. In all cultivars, the total leaf surface area of the untreated control plants (C), which received irrigation water only, was the smallest. The largest maximum leaf surface area (cm²) was recorded in the cultivar Korona (Figure 1). While in Korona and Sonata the difference between the control and the treated groups was substantial, in Sonata significant differences were detected only under the FQA and RM treatments. In Senga Sengana, the FQA treatment resulted in the largest maximum leaf surface area, representing a 53% increase compared with the C group. In Korona, the TY treatment produced a 44% larger maximum leaf surface area than the control. In Sonata, the RM treatment resulted in a 32% increase in maximum leaf surface area relative to the C group.

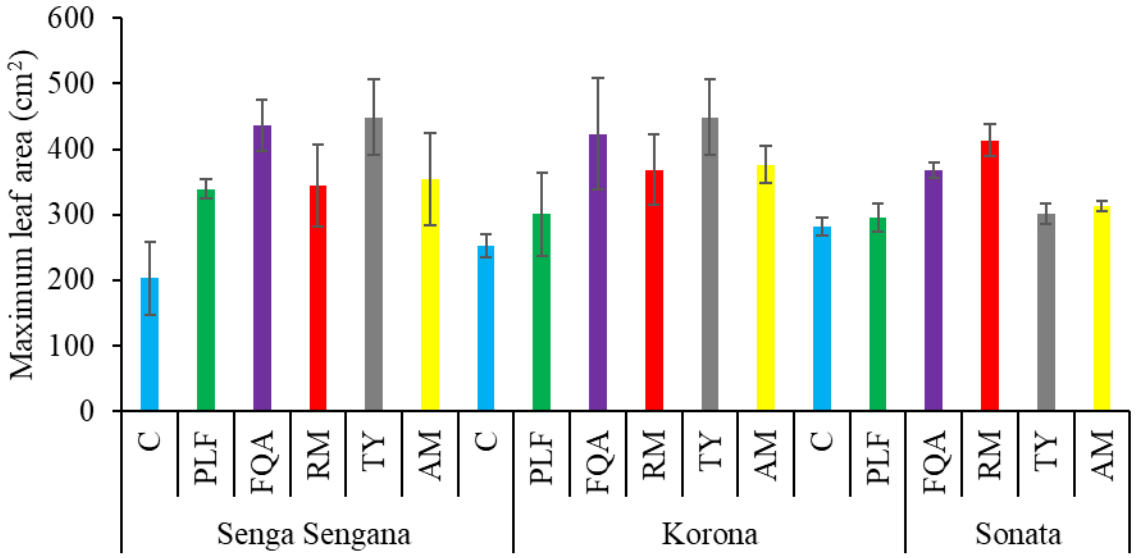

Figure 1 *Maximum leaf surface area in the three strawberry cultivars examined under the applied biostimulant treatments: C – control, PLF – Plantafol 20.20.20, FQA – FoliQ AscoVigor, RM – RhizoMagic, TY – TYTANIT and AM – Amalgerol*

Considering the results of leaf surface measurements, the biostimulant-treated Senga Sengana plants developed larger leaf areas than both the treated and untreated control plants (Figure 2a). The greatest increases in leaf surface area were observed under the TY and FQA treatments during the study period. Under both treatments, leaf surface area reached approximately 450 cm² by 22 June. The most dynamic leaf area expansion was recorded in response to the Tytanit treatment, with a 72% increase compared with the initial measurements. Under the FQA biostimulant treatment, the maximum leaf surface area increased by 64% relative to the values measured on 25 May. Moderate increases in leaf surface area were observed under the PLF, RM and AM treatments. According to the measurements, leaf surface area in the AM-treated group increased slowly at the beginning of the observation period but aligned with the other moderate-growth treatments after 1 June. The slowest growth occurred in the untreated control group,

which reached only around 200 cm² at the final measurement—54% lower than the largest maximum leaf surface area recorded in Senga Sengana.

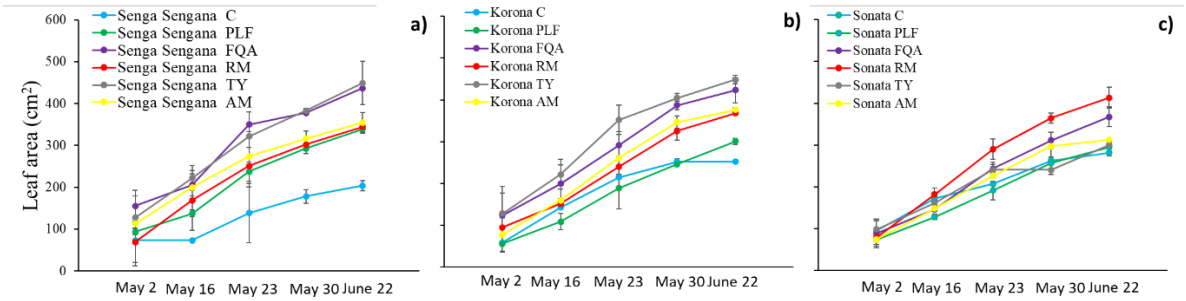

Figure 2 *Leaf surface area development in the three strawberry cultivars examined under the applied biostimulant treatments (Senga Sengana (a), Korona (b), Sonata (c)) under the applied biostimulant treatments: C – control, PLF – Plantafol 20.20.20, FQA – FoliQ AscoVigor, RM – RhizoMagic, TY – TYTANIT, AM – Amalgerol*

In the examination of leaf surface development in the cultivar Korona, the highest values were recorded in the TY-treated group, similarly to the observations made for Senga Sengana (Figure 2b). Leaf surface area increased under the Tytanit treatment partly because the treated plants developed five-lobed compound leaves instead of the typical trifoliate leaves characteristic of strawberry. Based on the measurements taken on 22 June, leaf surface area in Korona increased by 71% under the FQA treatment compared with the values recorded on 25 May, making this group the second highest in terms of maximum leaf surface area. Interestingly, no increase in leaf surface area was observed in the untreated group between 15 May and 22 June, whereas during the same period the control group exhibited the most intensive growth.

In the case of the cultivar Sonata, only small differences were observed between the untreated control and the treated groups with respect to maximum leaf surface area (Figure 2c). This is notable because in the other two cultivars, differences of nearly 200 cm² (Korona) and 250 cm² (Senga Sengana) were recorded between the groups with the largest and smallest leaf areas. In Sonata, however, the difference was only 131 cm², yet the largest leaf surface area (282 cm²) was measured in the untreated control group. The RM-treated Sonata plants displayed the highest leaf surface area values consistently after the measurements taken on 30 May. This treatment also showed the most dynamic leaf area expansion, with an 81% increase over the study period. Plants treated with FQA also developed relatively large leaf areas, although this was achieved through a slower growth trajectory; on 23 May, their leaf surface values were still below 90 cm². Under the AM treatment, an average weekly increase of 74 cm² was observed until 22 June, after which growth rate decelerated. In the TY treatment, no difference was observed in the final measurement compared with previous values; this treatment resulted in the smallest maximum leaf surface area among the biostimulant treatments for the cultivar Sonata. During the second measurement, the untreated control group exhibited the second highest leaf surface area. The PLF and C groups lagged behind in growth at later stages, and no large maximum leaf areas were recorded in these treatments.

Several international studies have reported increases in strawberry leaf surface area in response to biostimulant treatments (Ibrahim et al., 2021; Jiang et al., 2022; Marcellini et al., 2022; Rana et al., 2023; Mattner et al., 2023). Cassel et al. (2025), however, also noted that one effective approach to mitigating the negative effects of water deficit in strawberry is the application of biostimulants. In addition to reducing abiotic stress in many plant species, the use of biostimulants is frequently associated with increased strawberry yields and improved fruit quality (Wise et al., 2024).

4. Conclusions

Biostimulants offer valuable opportunities in crop production by enhancing nutrient use efficiency and reducing stress. In the experiment conducted, the application of each biostimulant, in addition to the baseline Plantafol 20.20.20 fertilisation, increased leaf surface area, from which a potential increase in yield can also be inferred. The cultivars included in the study are widely accessible and commonly used both by home gardeners and by commercial growers. Based on the results obtained for these three cultivars, the supplementary use of biostimulants is recommended. Further investigations involving additional biostimulant products may attract considerable interest in the future. By mapping the effects of foliar fertilisers, practical recommendations can be provided for both commercial producers and home gardeners regarding the expected impact of the applied treatments.

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Estimation of the areal evapotranspiration of the Ingói-berek in the Kis-Balaton wetland using Landsat-8 satellite images with two approaches

A kis-balatoni Ingói-berek területi evapotranszspirációjának becslése Landsat-8 műholdképek segítségével két megközelítéssel

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Abstract: When examining the water balance of lakes, the measurement and determination of evaporation and transpiration are the biggest problems. Evapotranspiration - as an output parameter of water balance- is very important in case of our largest lake, Lake Balaton and the associated Kis-Balaton Protection System. The evapotranspiration of the common reed (*Phragmites australis*) plays a decisive ecological role in the wildlife of the marshes. In case of Kis-Balaton, common reed is a significant factor due to the extent of its stands, which exceed 2,000 hectares. The latest solutions in evapotranspiration models are remote sensing models. We have tried to estimate the areal evapotranspiration with the red and near-infrared bands (NDVI, Normalized Difference Vegetation Index) of Landsat-8 satellite images using two different approaches: the use of FAO-56 potential evapotranspiration equation with local crop coefficients and the SEBAL model.

Keywords*: evapotranspiration; Landsat-8 satellite images; NDVI*

Összefoglalás: Állóvizeink vízháztartási mérlegének vizsgálata során a párolgás és párologtatás mérése, meghatározása jelenti az egyik legnagyobb problémát. Az evapotranszspiráció - mint a mérleg egyik legnagyobb kiadási paramétere - döntő fontosságú legnagyobb tavunk a Balaton és a hozzá tartozó Kis-Balaton Védelmi Rendszer működésében. A Kis-Balaton mocsarainak élővilágában meghatározó ökológiai szerepet betöltő közönséges nád (*Phragmites australis*) evapotranszspirációja jelentős tényező állományainak mérete miatt, mely a Kis-Balaton esetében 2000 hektárt meghaladó mértékű. Az evapotranszspirációs modellek legújabb megoldásait jelentik a távérzékeléses modellek. Landsat-8 műholdképek vörös és közeli infravörös spektrumaiból (NDVI) számítva végeztünk evapotranszspiráció becslést két módszer felhasználásával: helyben mért növénykonstansos megközelítést FAO-56 egyenlettel és a SEBAL modell futtatásával.

Kulcsszavak*: evaporanszsiráció, Landsat-8 műholdképek, NDVI*

1. Introduction

Many wetlands around the world are threatened by changes in water management, often with detrimental consequences for their ecosystems and the ecosystem services that are important to many people (Finlayson and D'Cruz, 2005).

The largest shallow freshwater lake in Europe is the Lake Balaton. Its natural filter, the Kis-Balaton wetland (KBW) is a crucial part of Lake Balaton's ecosystem, serving as a natural filter for the Zala River, which is the lake's primary water source (Hatvani et al., 2011). The site of this study, the Ingói-berek is a specific area within the Kis-Balaton wetland, and recent conservation efforts have focused on improving the habitat and preserving natural values in the Lake Balaton region.

Evapotranspiration (ET) is an important output component of the water balance. Accurate estimation of ET is crucial for optimal water resource management. The difficulties in calculating ET in wetlands can lead to inaccurate water balance estimations. Simple meteorological methods or off-site ET data are often used to estimate ET, but these approaches do not incorporate potentially important site-specific factors (Lott and Hunt, 2001).

Meteorological or climatological methods are based on-site point data, which cannot provide accurate approach of ET over large areas. Although the water balance method can estimate evapotranspiration at the watershed level, it works for a long time, usually one year, and cannot meet the requirements of short-term studies (Liu et al., 2006). Considering these problems, remote sensing methods are used to estimate actual ET (ETa), which provide pixel-scale ETa estimates for shorter periods over a large area. Most of these methods are based partly or fully on the energy balance principle, where net radiation is considered the main driver. The Surface Energy Balance ALgorithm (SEBAL) for land is a spatial ETa estimation method based on energy balance and satellite remote sensing techniques (Bastiaanssen et al., 1998).

The aim of this study was to detect the applicability of Landsat-8 satellite images in canopy cover detection (NDVI) as well as the use of SEBAL in ETa determination. The modelled ETa results were validated by locally measured estimations based on crop constants and use of FAO-56 equation.

2. Materials and Methods

An ETa study was carried out on the Ingói-berek, KBW at the end of August 2024. We chose the end of August as the sample day because the reed canopy had already reached its maximum size by this time. The area of Ingói-berek is about 440 ha, and one third of it is vegetation covered. The remaining part consists of fragmented reed and open water (Fig. 1).

The Landsat-8 L1 30 x 30 m resolution with less than 10% cloud cover images were downloaded from https://earthexplorer.usgs.gov on 28.08.2024.

Figure 1 *The NDVI of the Ingói-berek, Kis-Balaton wetland by Landsat-8*

We created a Normalized Differential Vegetation Index NDVI = (R-NIR)/(R+NIR) image from the red (R) and near-infrared (NIR) bands using the QGIS 3.28 (www.qgis.org) GIS software (Figure 1). We masked the 440-hectare Ingo area from the NDVI raster images. Then we classified the image by dividing the NDVI range into 3 equal parts. The upper interval: dense reed stand, the middle interval: transition between reed and water with submerged macrophyte, the lower interval: water with submerged macrophytes.

Calculation of ETa by locally measured data

The satellite images-based classification of the Ingói-berek was necessary due to the vegetation cover and the way of its ETa estimation by using crop coefficient and FAO-56 approach.

The daily reference evapotranspiration (ET_0) was calculated from the data of the Keszthely Agrometeorological Research Station (L: 46° 44', W: 17° 14' E: 124 m) using the FAO-56 formula (Allen et al., 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma\ \Delta(1 + 0.34\ u_2)} \qquad (1)$$

where Rn is the net surface radiation of the plant (MJ m^{-2} day^{-1}), G is the daily heat flux of the soil (MJ m^{-2} day^{-1}), T is the average daily temperature measured at a height of 2 m (°C), u2 is the wind speed measured at a height of 2 m (ms^{-1}), es is the saturation water vapor pressure (kPa), ea is the actual water vapor pressure (kPa), Δ is the slope of the water vapor pressure curve (kPa $°C^{-1}$), γ is the psychrometric constant (kPa $°C^{-1}$).

The actual evapotranspiration for the three classified areas was determined using the ETa plant constants for reed, submerged macrohytes and the transitional average of the two:

$$ET_a = K_c\ x\ ET_0 \qquad (2)$$

where Kc is the crop coefficient (Kc_reed: 1.23 (Anda, 2014), Kc_submerged_macrophytes: 1.04 (Anda,2016), Kc_average = transition: 1.14) and ET_0 is the daily reference evapotranspiration.

By multiplying the classified NDVI areas with the ETa we get the areal daily evapotranspiration for the Ingói-berek. We compared this value with the one calculated by SEBAL.

The SEBAL method

SEBAL calculates the total radiation and energy balance for each pixel. Evapotranspiration is derived from the instantaneous latent heat flux, λET (Wm^{-2}), and is calculated as the residual of the surface energy balance equation at the moment of satellite departure for each pixel:

$$R_n = G + H + \lambda ET \qquad (3)$$

where R_n is the net radiation in Wm^{-2},
G is the ground heat flux (Wm^{-2}),
H is the sensible heat flux (Wm^{-2}),
is the latent heat flux (Wm^{-2}), (λ is the latent
heat of evaporation, and ET is the evapotranspiration).

The net radiation (Rn) is calculated from the radiation balance of the earth's surface as follows:

$$R_n = (1 - \alpha)\ x\ R_s \downarrow + RL \downarrow - RL \uparrow - (1 - \varepsilon)\ x\ RL \downarrow \qquad (4)$$

where RS↓ is the incoming shortwave radiation (Wm^{-2}),
is the surface albedo (dimensionless),
RL↓ is the incoming longwave radiation (Wm^{-2}),
RL↑ is the outgoing longwave radiation (Wm^{-2}),
is the surface emissivity (dimensionless).

The ground heat flux (G) is estimated using the empirical relational function of Bastiaanssen (2000), using net radiance and some additional surface parameters such as albedo, surface temperature and normalized difference vegetation index (NDVI):

$$\frac{G}{R_n} = \frac{T_s}{\propto(0.0038\propto + 0.0074\propto^2)(1 - 0.98NDVI^4)} \qquad (5)$$

where Ts is the surface temperature in K.

The sensible heat flux (H) is a function of the temperature gradient, surface roughness and wind speed, and is therefore difficult to calculate due to the interaction of temperature gradient and surface roughness. The classical expression for sensible heat flux was given by Farah and Bastiaanssen (Farah and Bastiaanssen, 2001):

$$H = \rho\ x\ C_p\ x\ dT\ /\ r_{ah} \qquad (6)$$

Where H is the sensible heat flux,
the density of air (kg m^{-3}),
Cp is the specific heat of air (1.004 J/kg/K),
dT is the near-surface temperature difference in K,
and rah is the aerodynamic resistance to heat transport (m/s).

In the SEBAL model, a linear relationship is introduced between the surface temperature Ts and the calibrated dT based on the knowledge of two boundary conditions identified within the image, where the dT values can be calculated using the known H values at the two pixels.

$dT = aTs + b.$ (7)

To define the coefficients a and b, two pixels must be selected that represent extreme conditions of temperature and humidity, which are called hot and cold pixels. The cold pixel is a well-irrigated, fully covered cropland with a surface temperature (Ts) close to the air temperature (Ta). The hot pixel is a dry, bare agricultural area with a λET of 0. The two pixels connect the calculations of all other pixels between these two points. Starting from neutral stability assumptions, the sensible heat flux is iteratively estimated using the Monin-Obukhov atmospheric stability corrections.

Latent heat flux is the rate of latent heat loss at the surface due to evapotranspiration:

$$\lambda ET = R_n - G - H \quad (8)$$

Evapotranspiration for the current time (mm/h):

$$ET_{inst} = 3600\ x\ \frac{\lambda ET}{\lambda} \quad (9)$$

Where latent heat (J/K):

$$\lambda = 2.501 - (T_a - 273)\ x\ 0.002361 \quad (10)$$

The reference ET ratio:

$$ETrF = ET_{inst}/ETr \quad (11)$$

Where ETr is the reference ET for the given hour.
The daily ET is calculated from the daily reference ET:

$$ET_{24} = ETrF\ x\ ET_{r-24} \quad (12)$$

Where the cumulative 24-hour ETr for the satellite leap day:

$$ET_{r-24} = \sum_{h}^{24} ET_{r-h} \quad (13)$$

3. Results and Discussion

In the classified NDVI image of 28 August 2024, the three different areas are clearly distinguished in Figure 2: 61.5% reed, 28.2% transition between reed and water - submerged macrophytes, and 10.3% water - submerged macrophytes (Figure 2).

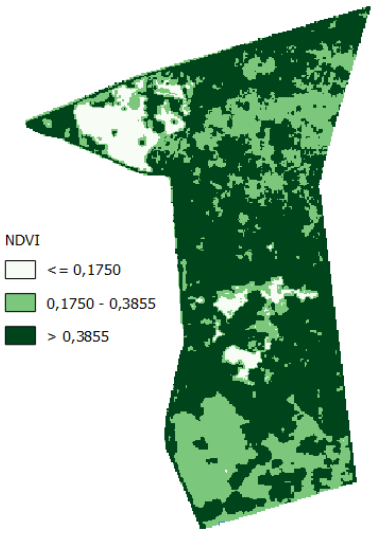
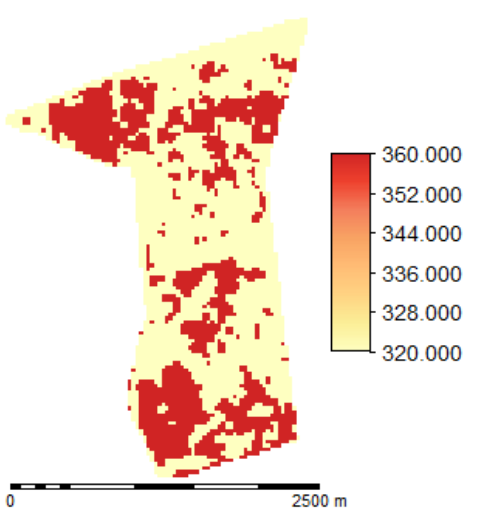
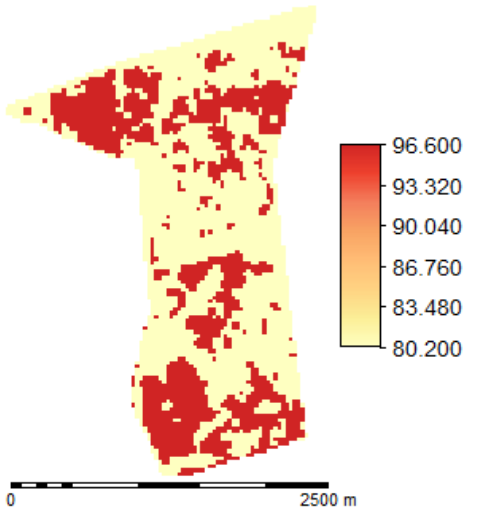


Figure 2 *The classified areas: white: water - submerged macrophytes, light green: transition, dark green: reed.*

We have summarized the energy balance components of the day (28.08.2024) calculated with SEBAL (Rn, G, H, λET) and the hourly and daily evapotranspiration calculated for the satellite time in Figure 3.

28.08.2024 Rn [W m^{-2}]	28.08.2024 G [W m^{-2}]
	
28.08.2024 H [W m^{-2}]	28.08.2024 λET [W m^{-2}]

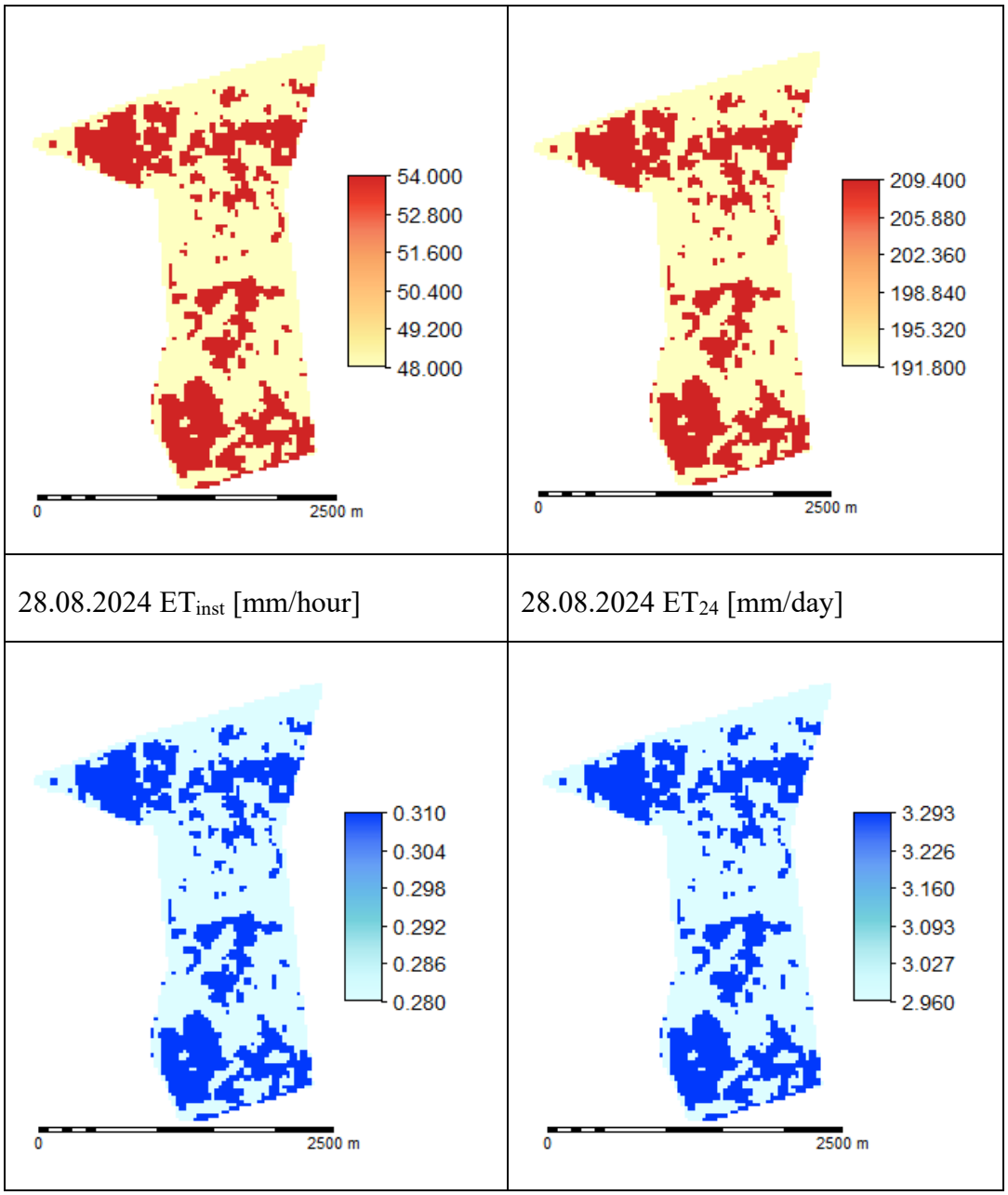


Figure 3 *SEBAL results for 28 August 2024 (Rn - net radiation, G - ground heat flux, H - sensible heat flux, λET - latent heat flux, ETins - ET for the current time, ET24 - 24-hour ET)*

The daily reference evapotranspiration calculated with the FAO-56 formula was 3.52 mm on the sample day of 28 August 2024. The comparison of the daily evapotranspiration calculated with the FAO-56 formula in Figures 4 and 5 clearly shows that SEBAL underestimates by 24%.

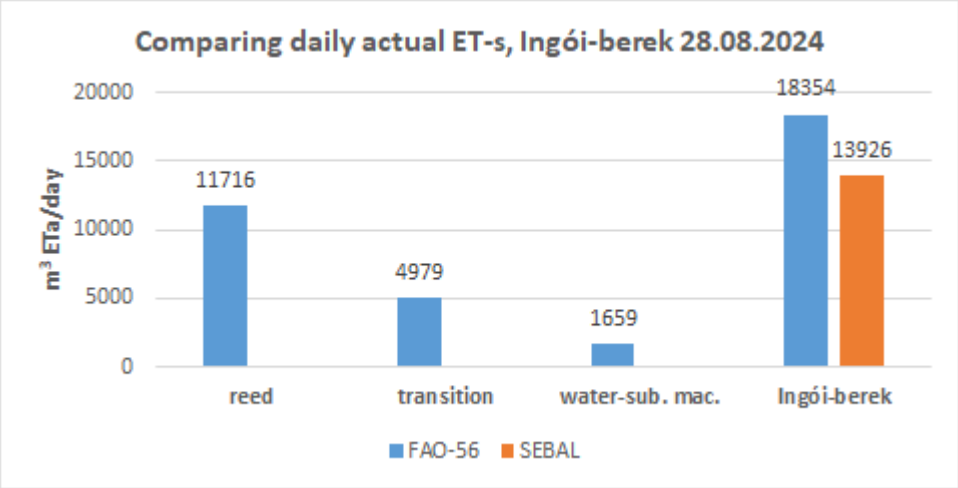


Figure 4 *Comparison of daily evapotranspiration in m³ for Ingói-berek 2024.08.28*

The daily evapotranspiration in m^3/day can be seen in Figure 4. For reed dominated area 11716 m^3/day, for the transitional area 4979 m^3/day and the water – submerged macrophytes area 1659 m^3/day were calculated. The actual evapotranspiration for whole area of Ingói-berek was 18354 m^3/day, which clearly exceeds the SEBAL-modelled value of 13926 m^3/day.

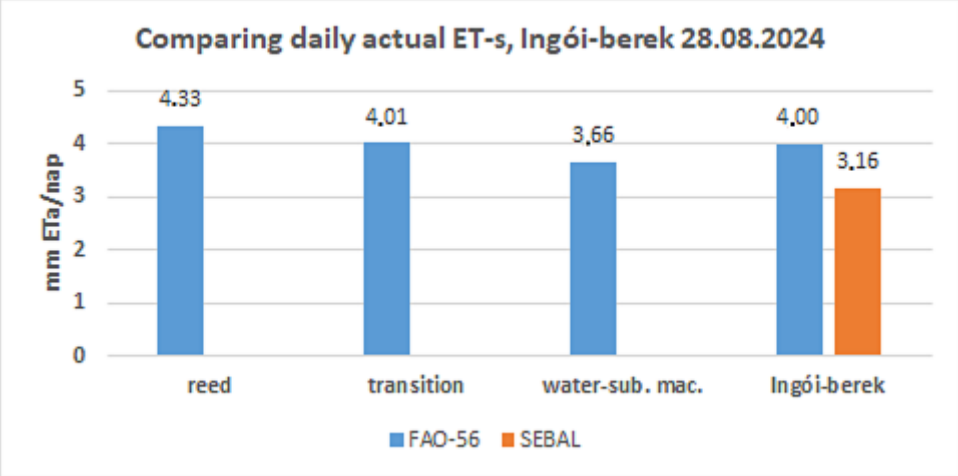


Figure 5 *Comparison of daily evapotranspiration in mm for Ingói-Berek 2024.08.28.*

The daily evapotranspiration in mm/day can be seen in Figure 5. For reed dominated area 4.33 mm/day, for the transitional area 4.01 mm/day and the water – submerged macrophytes area 3.66 mm/day were calculated. The actual evapotranspiration for whole area of Ingói-berek was 4.00 mm/day, which clearly exceeds the SEBAL-modelled value of 3.16 mm/day.

4. Conclusions

Calculating regional evaporation from freely available satellite remote sensing images is a complex but spectacular method. Satellite imagery has a distinct advantage when it comes to area coverage. Satellites can capture images of various areas, including remote and inaccessible regions. The Ingói-berek also provides a good example of estimating the coverage of hard-to-reach areas. The definition of evapotranspiration itself is quite problematic; each approach is

subject to error, albeit to varying degrees. If we add to this the approximation error in the basic coverage data, the ET estimate as the largest output member in the water balance, deteriorates it further.

The modelling approach in ET estimation increasingly gaining ground in the literature. Based on local daily ETa calculation (crop coefficient), the difference between the daily modelled ETa amount 24%, which can be considered acceptable. In the future, satellite imagery will be indispensable for delineating hard-to-reach areas, which can be combined with the SEBAL model to estimate ETa, accurately. It can also be considered an advantage that satellite imagery presents a cost-effective solution compared to drones.

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