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 szamóca 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 (cm^2) 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.

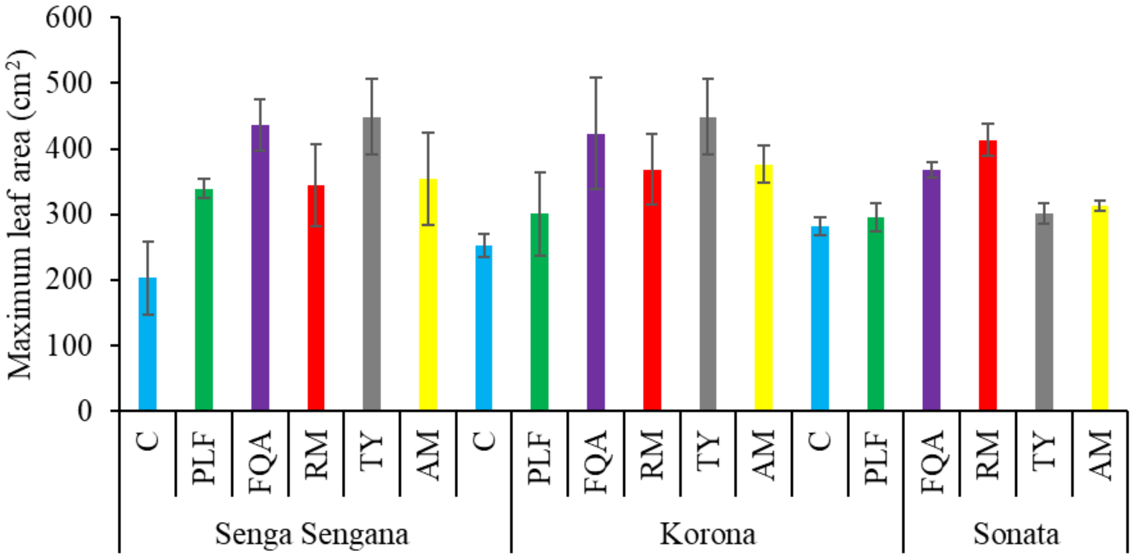

Figure 1 *Maximum leaf surface area in the three strawberry cultivars examined under the applied biostimulant treatments: C – control, PLF – Plantafol 20.20.20, FQA – FoliQ AscoVigor, RM – RhizoMagic, TY – TYTANIT and AM – Amalgerol*

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 cm^2 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.

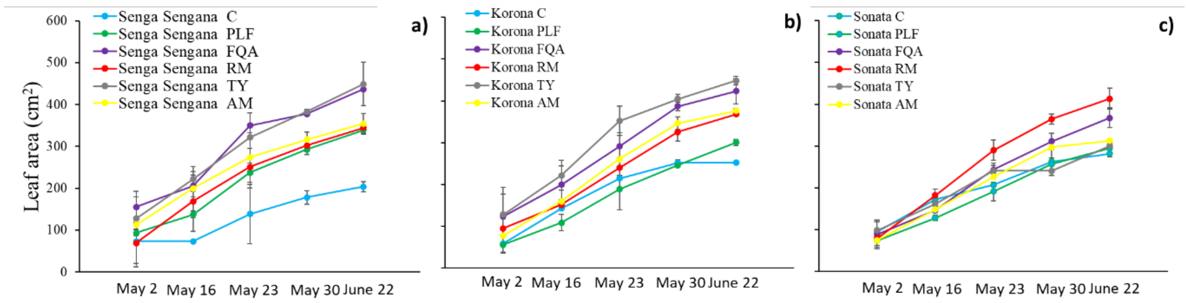

Figure 2 *Leaf surface area development in the three strawberry cultivars examined under the applied biostimulant treatments (Senga Sengana (a), Korona (b), Sonata (c)) under the applied biostimulant treatments: C – control, PLF – Plantafol 20.20.20, FQA – FoliQ AscoVigor, RM – RhizoMagic, TY – TYTANIT,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