Voćarstvo, 59, 225–226 (2025), 105–115
Journal of Pomology, 59, 225–226 (2025), 105–115
https://doi.org/10.18485/pomology.2025.59.225_226.4

UDC: 634.711:631.461.51
Original scientific paper
Originalni naučni rad

Microalgae-based biostimulants change physiological, agronomic and fruit quality traits of 'Solu Red' and 'Wakefield' raspberries

Jasminka Milivojević[1*](0000-0002-1158-393X), Slavica Spasojević[1] (0009-0000-2367-1825), Jovan Radaković[1], Dragan Radivojević[1] (0000-0003-4378-6544), Miloš Perišić[2]

[1]*University of Belgrade, Faculty of Agriculture, Nemanjina 6, 11080 Zemun-Belgrade, Republic of Serbia*
[*]*E-mail: jasminka@agrif.bg.ac.rs*
[2]*Floriva d.o.o., Radaljevo bb, 32252 Radaljevo, Republic of Serbia*

Received: 12 October 2025; Accepted: 24 October 2025

Abstract. This study illustrates the effect of the microalgae-based biostimulants 'Algafert' (0.75% N; 7.40% P_2O_5, 3.20% K_2O, 5.60% free amino acids) and 'Biofat 600' (2.70% N, 6.70% Ca, 0.10% P_2O_5, 0.10% K_2O, 6% free amino acids) on the leaf concentration of chlorophyll (SPAD) and nitrogen (mg g^{-1}), cane architecture traits, productivity, biometric and chemical fruit properties of raspberry cultivars 'Solu Red' and 'Wakefield'. This research was carried out in a raspberry plantation established in 10-l pots filled with coco peat in the spring of 2022 (company 'Floriva', municipality of Ivanjica). The following treatments were applied: T_1 – 'Biofat 600' (2 foliar applications, 2 l ha^{-1} per application); T_2 – 'Algafert' (2 foliar applications, 1 l ha^{-1} per application) + 'Biofat 600' (1 foliar application, 2 l ha^{-1}) and T_0 – control treatment. The first application was performed on May 17, 2024 (40% of opened flowers) followed by the second application during the fruit setting and growth. Both biostimulants' treatments significantly increased concentrations of chlorophyll and nitrogen after the second application compared to the control. 'Wakefield' exhibited significantly higher chlorophyll and nitrogen concentrations compared to 'Solu Red'. A significantly higher number of fruiting laterals (32.6) and yield per cane (1261.3 g) were recorded in 'Solu Red', while the number of fruits per cane did not differ significantly between the tested cultivars. 'Solu Red' showed significantly higher values for the fruit volume-related traits and total acids compared to 'Wakefield'. This study revealed that microalgae-based biostimulants offer a unique opportunity to strengthen the plants' capacity to cope with challenges amplified by climate change.

Key words: 'Algafert', 'Biofat 600', raspberry, leaf chlorophyll, yield, fruit quality

Introduction

Raspberry (*Rubus idaeus* L.) is a highly valuable soft fruit increasingly challenged by climate variability and tightening sustainability standards, especially in the area of mineral fertilizers application. Given that continuous and unbalanced use of mineral fertilizers adversely affects the environment, the application of various biostimulants could be a new technological approach to promote sustainable and efficient nutrient management (Handoko & Lin, 2025; Žunić et al., 2024; Milivojević et al., 2024). The Serbian raspberry industry faces multiple constraints, including escalate negative effects of climatic factors (spring frost, drought and heat during the summer) and unsuitable heavy soils, as well as the dominant presence of old cultivars that possess only modest tolerance to abiotic stress, which endangers both yield and fruit quality

(Manganaris et al., 2024). Therefore, introduction of new cultivars with improved tolerance or resistance to stress conditions, along with adoption of innovative soilless cultivation techniques provide an ideal approach for developing an integrated strategy that will help the raspberry industry adapt to increasing climatic instability. Moreover, soilless raspberry cultivation is becoming widely adopted in Europe, making the selection of substrate and cultivation management essential to reach optimal fruit yield and quality (Qiu et al., 2017).

Additionally, the application of microalgae-based biostimulants may have an important role to expand the resiliency and viability of plants, contributing to the improvement of yield, vegetative growth and physico-chemical fruit characteristics (Žunić et al., 2024; Ganugi et al., 2021). These formulations are considered environmentally friendly substances and have been proposed as a viable alternative to the use of conventional fertilizers (Rouphael & Colla, 2020). Specifically, the positive action of microalgae-based products relates to the promotion of nutritional efficiency and tolerance to abiotic stress (Castiglione et al., 2021), exerting a beneficial effect not only on agronomic or crop quality traits, but also on physiological responses of plants (Mannino et al., 2022). Numerous studies have focused on the application of microbial-based products across various plant species, indicating beneficial effects in terms of increasing plant height, leaf number, yield and antioxidant activity (Žunić et al., 2024; Morillas-Espana et al., 2022; Park et al., 2022; Suleiman et al., 2020). Therefore, the main objectives of this research were to: (1) identify variability in physiological [leaf chlorophyll (SPAD) and nitrogen concentration (mg g^{-1})], agronomic (cane architecture, productivity), and fruit quality (biometric and chemical fruit properties) traits between the two raspberry cultivars 'Solu Red' and 'Wakefield'; (2) assess the cultivar-specific response associated with foliar application of the microalgae-based biostimulants 'Algafert' (0.75% N; 7.40% P_2O_5, 3.20% $K2_5O$, 5.60% free amino acids) and 'Biofat 600' (2.70% N, 6.70% Ca, 0.10% P_2O_5, 0.10% K_2O, 6% free amino acids). This integrative study aims to provide both practical and scientific insights to enhance physiological processes and agronomic performance of two soilless grown raspberry cultivars under challenging environmental conditions.

Materials and Methods

The field research was carried out in a raspberry plantation of the company 'Floriva' located in the municipality of Ivanjica (southwestern Serbia, 43°37′07.3″ N, 20°10′41.2″ E, 468 m altitude) in 2024. Certified nursery plants of the raspberry cultivars 'Solu Red', originating from Italy, and 'Wakefield', originating from New Zealand, were planted in spring 2022 in 10-l pots filled with coco peat (Galuku, Australia). Pots were spaced 0.4 m apart in a row and 2.1 m between rows. Two floricanes per pot were maintained and supported by a trellis system. Plants were fertigated using a drip irrigation system with two emitters, delivering water at a rate of 3 l per pot per hour. Irrigation was adjusted to the plant's water requirements and calculated according to the evapotranspiration values. The nutrient solution consisting of NO_3- (6 mM), $H_2PO_4^{-1}$ (1 mM), SO_4^{2-} (1.5 mM), NH_4^+ (0.6 mM), K^+ (3 mM), Ca^{2+} (4 mM), Mg^{2+} (4 mM), Fe^{2+} (30 μM), Mn^{2+} (20 μM), Zn^{2+} (8 μM), B (12 μM), Cu (1.75 μM) and Mo (0.75 μM) was applied following the recommendation of Valentinuzzi et al. (2018). Fertigation was carried out five times per week from the end of April to the middle of July in 2024. The nutrient solution was characterized by a pH value of around 5.5 and mean Electrical Conductivity (EC) of 2000 Ms cm^{-1}.

The two microalgae-based biostimulants 'Algafert' (0.75% N; 7.40% P_2O_5, 3.20% K_2O, 5.60% free amino acids) and 'Biofat 600' (2.70% N, 6.70% Ca, 0.10% P_2O_5, 0.10% K_2O, 6% free amino acids) produced by the Biorizon Biotech company (Almeria, Spain) were applied foliarly to the raspberry plants using the following treatments: T_1 – 'Biofat 600' (2 foliar applications, dose 2 l ha^{-1} per application); T_2 – 'Algafert' (2 foliar applications, dose 1 l ha^{-1} per application) + 'Biofat 600' (1 foliar application, dose 2 l ha^{-1} per application) and T_0 – control treatment (without application). The first application was performed on May 17, 2024 (40% open flowers), followed by the second application on May 29, 2024 (set and fruit development). A total of 12 canes per cultivar were treated with microalgae-based biostimulants (6 pots with 2 canes), and testing was performed in 3 repetitions per 4 canes. The control treatment consisted of 12 canes without the application of biostimulants. Seven days after the completion of each application and treatment, the leaf concentrations of chlorophyll

(SPAD) and nitrogen (mg g^{-1}) were measured using the MC-100 chlorophyll meter (Amtast, USA).

Parameters of cane architecture [cane height (cm) and diameter (mm), number of fruiting laterals per cane and length of laterals (cm)] were measured by standard morphometric methods. The number of fruits per cane was determined by counting, while yield per cane was calculated by summing the weight of the freshly harvested fruit from all harvests (gram per cane).

The fully ripe fruit samples of the tested cultivars were collected at the second harvest (end of June) and used to determine biometric and chemical fruit properties, such as: fruit weight (g), fruit height (mm), fruit width (mm), fruit shape index, number of drupelets, total soluble solids content (TSS, %), and total acids (TA, %). A sample of 30 fruits per replicate was weighed on a technical scale (Acom JW-1, ACOM, Seoul, South Korea) with an accuracy of 0.01 g and used for counting drupelets. Fruit height (mm) and fruit width (mm) were measured using a digital caliper (Prowin, Shanghai, China). The fruit shape index was determined as the ratio of the maximum height and width. TSS was determined using a digital refractometer (Pocket PAL-1; Atago, Tokyo, Japan). The results are presented as a percentage of dissolved solids in the fruit extract. TA content was measured by titrating samples with 0.1 M NaOH to an endpoint of pH 8.1 using a digital burette, and acidity was expressed as a percentage of citric acid equivalent. Analyses were performed in the laboratory of the Department of Fruit Science, Faculty of Agriculture, University of Belgrade.

Data analysis was performed using SPSS 17.0 Statistics (IBM, Armonk, NY, USA). The significant differences between the cultivars, treatments, and their interaction were estimated by two-way analysis of variance (ANOVA) at $p \leq 0.05$. The significance of the differences between the mean values was determined using the LSD test at $p \leq 0.05$.

Results and Discussion

The average values of cane architecture parameters for raspberry cultivars ‘Solu Red’ and ‘Wakefield’ treated with microalgae-based products are presented in Table 1. No significant differences in cane height and diameter were observed between both tested cultivars and microalgae-based treatments. The number of fruiting laterals per cane was significantly higher in cultivar ‘Solu Red’ (32.6), with no significant effect of the applied biostimulant treatments on this trait. Cultivar ‘Wakefield’ had significantly higher length of the laterals (34.1 cm) than cultivar ‘Solu Red’ (27.1 cm). Our findings align with those of Stephens et al. (2012), who reported that the cultivar ‘Wakefield’ forms very vigorous and thick canes, which tend to branch in the upper parts. The length of the laterals was significantly reduced in the T_1 treatment (27.9 cm), whereas no significant differences were observed between the control and T_2 treatments. The interaction effect of cultivar × biostimulant treatment on the cane architecture traits was not significant.

In a few studies, it can also be outlined that biostimulants do not act by supplying essential nutrients or directly inducing plant morphological changes (Kaushal et al., 2023; du Jardin, 2015). However, conflicting results exist regarding the ability of microalgae-based biostimulants to change plant morphological traits, with reports indicating that they can promote plant height, leaf number and yield (Žunić et al., 2024; Park et al., 2022; Suleiman et al., 2020) and increase pigment content and sugars (Cordeiro et al., 2022). Microalgae are rich in chlorophyll, proteins, polysaccharides, vitamins, essential amino acids and antioxidant compounds, which modulate existing physiological and biochemical processes, such as photosynthesis, thereby helping plants to express their genetic potential more effectively (Handoko & Lin, 2025; de Morais et al., 2015).

In our study, changes in leaf chlorophyll content were observed between both tested cultivars and biostimulant treatments (Table 2). Comparing cultivars, ‘Wakefield’ had significantly higher chlorophyll content than the cultivar ‘Solu Red’. A significant increase in mean leaf chlorophyll content was registered after the second application in T_1 and T_2 treatments (43.98 and 43.82 SPAD, respectively), while the lowest chlorophyll content was recorded in the control treatment (37.45 SPAD). The cultivar ‘Wakefield’ showed the highest chlorophyll content after the second application of the biostimulant in the T_2 treatment (46.8 SPAD). In contrast, the lowest leaf chlorophyll content was recorded in the ‘Solu Red’ cultivar in the control treatment (33.87 SPAD). Haroun & Hussein (2003) also recorded an increment in chlorophyll content in

Table 1. Cane architecture traits of raspberry cultivars 'Solu Red' and 'Wakefield' treated by microalgae-based products
Tabela 1. Karakteristike arhitekture izdanka sorti maline Solu Red i Wakefield tretiranih proizvodima na bazi mikroalgi

Cultivar/Treatment *Sorta/Tretman*	Cane height *Dužina izdanka* (cm)	Cane diameter *Prečnik izdanka* (mm)	Number of fruiting laterals per cane *Broj rodnih prirasta po izdanku*	Length of laterals *Dužina rodnih prirasta* (cm)
		Cultivar/*Sorta*		
'Solu Red'	175.5 ± 1.39	9.55 ± 0.20	32.6 ± 1.19 a	27.1 ± 0.94 b
'Wakefield'	180.2 ± 2.05	9.58 ± 0.09	23.5 ± 0.43 b	34.1 ± 0.90 a
Statistical significance	ns	ns	*	*
Statistička značajnost	nz	nz	*	*
		Treatment/*Tretman*		
T_0	174.6 ± 1.87	9.2 ± 0.18	27.6 ± 2.00	31.9 ± 1.42 a
T_1	178.8 ± 2.22	9.69 ± 0.18	28.1 ± 2.51	27.9 ± 1.63 b
T_2	180.1 ± 2.50	9.80 ± 0.10	28.3 ± 2.42	32.0 ± 2.10 a
Statistical significance	ns	ns	ns	*
Statistička značajnost	nz	nz	nz	*
		Interaction/*Interakcija*		
'Solu Red' × T_0	174.7 ± 2.68	9.05 ± 0.34	31.3 ± 2.45	29.4 ± 1.74
'Solu Red' × T_1	175.5 ± 0.51	9.77 ± 0.40	32.9 ± 2.89	24.6 ± 1.17
'Solu Red' × T_2	176.2 ± 3.89	9.82 ± 0.12	33.5 ± 1.15	27.4 ± 0.50
'Wakefield' × T_0	174.4 ± 3.20	9.34 ± 0.14	24.0 ± 0.91	34.4 ± 0.91
'Wakefield' × T_1	182.3 ± 3.60	9.61 ± 0.03	23.3 ± 0.24	31.2 ± 0.90
'Wakefield' × T_2	184.0 ± 1.04	9.78 ± 0.19	23.1 ± 1.03	36.5 ± 0.94
Statistical significance	ns	ns	ns	ns
Statistička značajnost	nz	nz	nz	nz

Means ± standard errors marked with different letters within the same column indicate statistically significant differences, as determined by the LSD post hoc test at $p \leq 0.05$. * – significance at $p \leq 0.05$, ns - not significant / *Srednje vrednosti ± standardna greška označene različitim slovnim oznakama u okviru kolone ukazuju na statistički značajne razlike prema testu NZR za $p \leq 0.05$. * – statistički značajno pri $p \leq 0.05$, nz – nije značajno.*

strawberry plants treated with microalgae, which resulted in an increase in the leaf area and plant height. The leaf nitrogen content was also significantly higher in the cultivar 'Wakefield' (16.21 mg g^{-1}) compared to the cultivar 'Solu Red' (14.67 mg g^{-1}). The nitrogen was present in leaves at the highest amounts after the second application of the microalgae-based biostimulant 'Biofat 600' in T_1 treatment and after the second application of 'Algafert' and 'Biofat 600' in T_2 treatment (16.55 and 16.32 mg g^{-1}, respectively). The lowest values of leaf nitrogen content were recorded in the control treatment (14.67–14.72 mg g^{-1}). In the 'Solu Red' cultivar, a significant increase in the leaf nitrogen content was registered after the second application in the T_1 treatment compared to the other applied treatments (16.27 mg g^{-1}). On the other hand, 'Wakefield' cultivar significantly increased leaf nitrogen content after the second application of microalgae-based biostimulants in T_2 and T_1 treatments (17.20 and 16.83 mg g^{-1}, respectively).

The yield-related parameters of the raspberry cultivars 'Solu Red' and 'Wakefield' treated with microalgae-based products are shown in Graph 1. Although the tested cultivars had an approximately number of fruits per cane, 'Solu Red' was a more productive cultivar with approximately 22% higher yield per cane (1261.3 g) compared to 'Wakefield'. Interestingly, observations made in a trial on the cultivar 'Wakefield' showed that it had significant advantages over the commercial cultivar 'Meeker' in terms of higher yield and fruit quality (Stephens et al., 2012).

Variation in the yield potential of the tested raspberry cultivars was also observed between the treatments in our study, with the combined application of

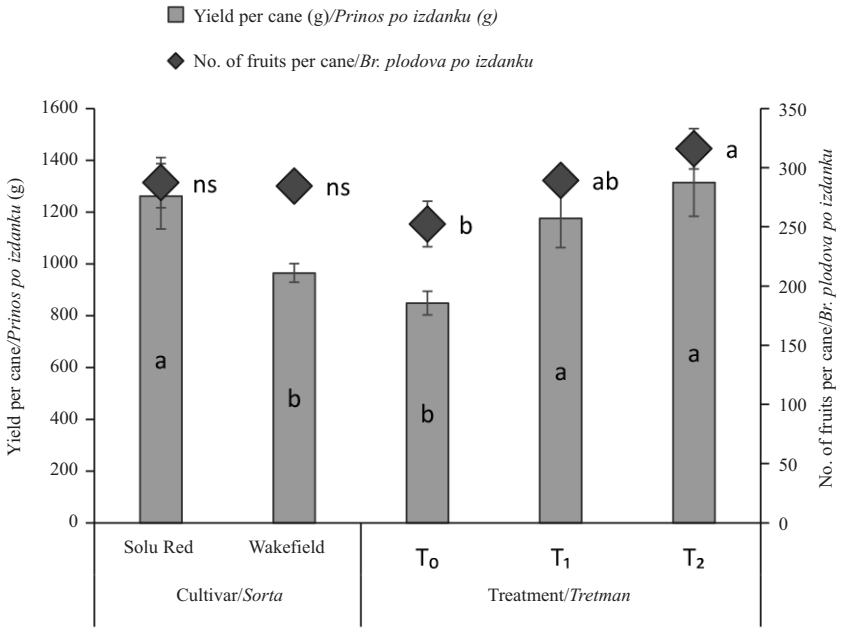
Table 2. Chlorophyll (CHL) and nitrogen (N) content in leaves of the raspberry cultivars 'Solu Red' and 'Wakefield' treated with microalgae-based products
Tabela 2. Sadržaj hlorofila (CHL) i azota (N) u listu maline sorti Solu Red i Wakefield tretiranih proizvodima na bazi mikroalgi

Cultivar/Treatment *Sorta/Tretman*	CHL (SPAD)	N (mg g^{-1})
	Cultivar/*Sorta*	
'Solu Red'	38.33 ± 0.78 b	14.67 ± 0.24 b
'Wakefield'	43.06 ± 0.55 a	16.21 ± 0.18 a
Statistical significance *Statistička značajnost*	* *	* *
	Treatment/*Tretman*	
T_0 1st application	37.45 ± 1.61 c	14.67 ± 0.52 d
T_0 2nd application	40.03 ± 0.43 b	14.72 ± 0.29 cd
$T_1$1st application	39.70 ± 0.96 b	15.22 ± 0.30 b
T_1 2nd application	43.98 ± 0.55 a	16.55 ± 0.22 a
T_2 1st application	39.18 ± 1.77 b	15.17 ± 0.54 bc
T_2 2nd application	43.82 ± 1.37 a	16.32 ± 0.42 a
Statistical significance *Statistička značajnost*	* *	* *
	Interaction/*Interakcija*	
'Solu Red'×T_0 1st application	33.87 ± 0.23 i	13.53 ± 0.26 g
'Solu Red'×T_0 2nd application	39.23 ± 0.18 f	14.13 ± 0.03 fg
'Solu Red'×T_1 1st application	37.67 ± 0.29 g	14.60 ± 0.12 ef
'Solu Red'×T_1 2nd application	43.07 ± 0.22 c	16.27 ± 0.07 bc
S'olu Red'×T_2 1st application	35.33 ± 0.87 h	14.03 ± 0.38 fg
'Solu Red'×T_2 2nd application	40.83 ± 0.64 e	15.43 ± 0.15 d
'Wakefield'×T_0 1st application	41.03 ± 0.28 e	15.80 ± 0.15 cd
'Wakefield'×T_0 2nd application	40.83 ± 0.50 e	15.30 ± 0.29 de
'Wakefield'×T_1 1st application	41.73 ± 0.64d e	15.83 ± 0.23 cd
'Wakefield'×T_1 2nd application	44.90 ± 0.78 b	16.83 ± 0.41 ab
'Wakefield'×T_2 1st application	43.03 ± 0.37 cd	16.30 ± 0.06 bc
'Wakefield'×T_2 2nd application	46.80 ± 0.21 a	17.20 ± 0.25 a
Statistical significance *Statistička značajnost*	* *	* *

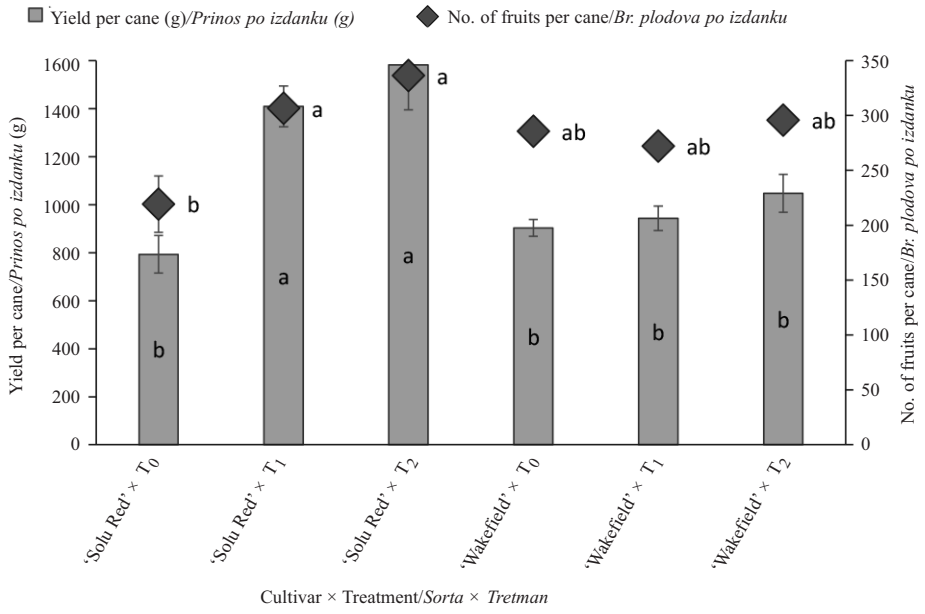
Means ± standard errors marked with different letters within the same column indicate statistically significant differences, as determined by the LSD post hoc test at $p \leq 0.05$. * – significance at $p \leq 0.05$; 1st application – of biostimulants; 2nd application of biostimulants / *Srednje vrednosti ± standardna greška označene različitim slovnim oznakama u okviru kolone ukazuju na statistički značajne razlike prema testu NZR za $p \leq 0.05$. * – statistički značajno pri $p \leq 0.05$; Prva aplikacija biostimulatora; Druga aplikacija biostimulatora.*

the biostimulants 'Algafert' and 'Biofat 600' (T_1) leading to a significant increase in the number of fruits per cane compared to the control. An increase in yield per cane was significant in both tested microalgae-based treatments (T_1 and T_2) in comparison to the control treatment. The cultivar × treatment interaction effect significantly influenced the yield parameters only in 'Solu Red' (Graph 2). Namely, the control treatment significantly reduced the number of fruits and yield per cane of this cultivar compared to the T_1 and T_2 treatments, between which no significant differences were recorded.

Fruit quality is defined by biometric traits and chemical composition, which can differ greatly depending on the cultivar, maturity stage, harvest time, growing system, and environmental factors (Spasojević et al., 2024; Milivojević et al., 2011). In our study, the 'Solu Red' cultivar showed significantly higher values for the fruit weight, height and width compared to the cultivar 'Wakefield' (Table 3). These



Graph 1. The yield parameters of the raspberry cultivars 'Solu Red' and 'Wakefield' treated with microalgae-based products
Grafikon 1. Parametri rodnosti sorti maline Solu Red i Wakefield tretiranih proizvodima na bazi mikroalgi



Graph 2. The interaction effects of the cultivar and treatment on the yield parameters of 'Solu Red' and 'Wakefield' raspberry cultivars treated with microalgae-based products
Grafikon 2. Interaktivni efekat sorte i tretmana na parametre rodnosti sorti maline 'Solu Red' i 'Wakefield' tretiranih proizvodima na bazi mikroalgi

findings are comparable to a report of Stephens et al. (2012) for the cultivar 'Wakefield', which was observed to have medium-sized fruit in the Pacific Northwest. Raspberries produce aggregate fruits composed of many small units (drupelets), which determine the size and shape of the fruit (Milivojević, 2022). Thus, considerable changes were also recorded in the fruit shape index between the cultivars tested, corresponding to a flattened round ('Wakefield') or round conical forms ('Solu Red'). The average number of drupelets per fruit ranged from 65.3 ('Wakefield') to 85.6 ('Solu Red'). Most parameters of biometrical fruit traits, except for fruit shape index, were positively affected by both the T_1 and T_2 biostimulant treatments, while the interaction effect of cultivar × treatment was not significant. The evaluation of biometric and chemical fruit quality traits represents an important task to better identify the commercial exploitation potential of newly introduced floricane fruiting raspberry cultivars.

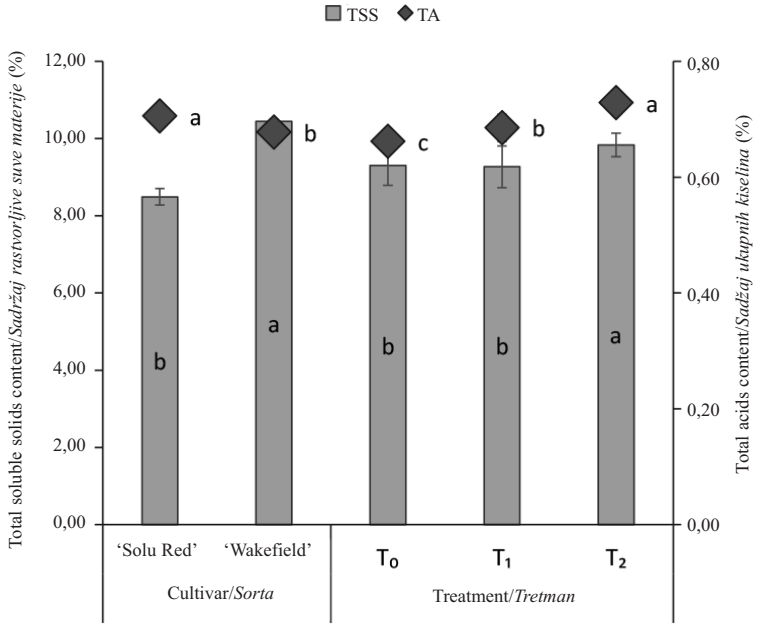
The obtained results of TSS and TA shown in Graph 3 indicated that the 'Wakefield' cultivar had a considerably higher TSS (10.44%) compared to the cultivar 'Solu Red' (8.49%), which was characterized by a greater level of TA (0.71%). As opposed to our results, Stephens & Enfield (2012) found a slightly higher amount of TSS in machine-harvested fruits of 'Wakefield' cultivar. The combined application of the 'Algafert' and 'Biofat 600' (T2) caused a significant increase in both the TSS and TA content in the fruit compared to the use of 'Biofat 600' alone (T_1) and the control treatment.

The interaction effect of cultivar × treatment showed a significant increase in the TSS content only in

Table 3. Biometric characteristics of the raspberry cultivars 'Solu Red' and 'Wakefield' treated with microalgae-based products
Tabela 3. Biometrijske karakteristike ploda maline sorti Solu Red i Wakefield tretiranih proizvodima na bazi mikroalgi

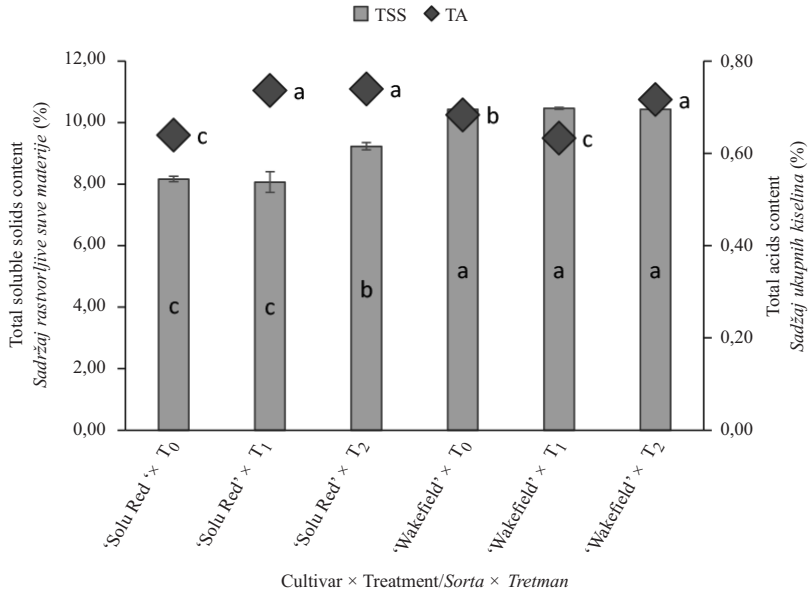
Cultivar/Treatment *Sorta/Tretman*	Fruit weight *Masa ploda* (g)	Fruit height *Visina ploda* (mm)	Fruit width *Širina ploda* (mm)	Fruit shape index *Index oblika ploda*	No. of drupelets in fruit *Br. koštunica u plodu*
			Cultivar/*Sorta*		
'Solu Red'	4.32 ± 0.19 a	19.77 ± 0.24 a	19.98 ± 0.33 a	0.99 ± 0.01 a	85.6 ± 1.97 a
'Wakefield'	3.39 ± 0.09 b	17.72 ± 0.28 b	18.86 ± 0.23 b	0.94 ± 0.01 b	65.3 ± 1.60 b
Statistical significance	*	*	*	*	*
Statistička značajnost	*	*	*	*	*
			Treatment/*Tretman*		
T_0	3.40 ± 0.13 b	18.05 ± 0.44 b	18.60 ± 0.22 b	0.97 ± 0.02	71.4 ± 4.07 b
T_1	4.03 ± 0.27 a	18.82 ± 0.60 a	19.53 ± 0.39 a	0.96 ± 0.01	74.5 ± 4.66 b
T_2	4.14 ± 0.30 a	19.37 ± 0.47 a	20.12 ± 0.37 a	0.96 ± 0.01	80.4 ± 5.49 a
Statistical significance	*	*	*	ns	*
Statistička značajnost	*	*	*	nz	*
			Interaction/*Interakcija*		
'Solu Red' × T_0	3.64 ± 0.14	18.97 ± 0.23	18.87 ± 0.29	1.01 ± 0.01	79.8 ± 2.40
'Solu Red' × T_1	4.59 ± 0.17	20.13 ± 0.03	20.33 ± 0.23	0.99 ± 0.01	84.7 ± 0.49
'Solu Red' × T_2	4.74 ± 0.20	20.20 ± 0.36	20.73 ± 0.41	0.98 ± 0.01	92.2 ± 1.07
'Wakefield' × T_0	3.17 ± 0.12	17.13 ± 0.27	18.33 ± 0.29	0.94 ± 0.02	62.9 ± 2.40
'Wakefield' × T_1	3.47 ± 0.12	17.50 ± 0.20	18.73 ± 0.23	0.94 ± 0.01	64.3 ± 2.27
'Wakefield' × T_2	3.53 ± 0.19	18.53 ± 0.52	19.50 ± 0.35	0.95 ± 0.01	68.7 ± 3.28
Statistical significance	ns	ns	ns	ns	ns
Statistička značajnost	nz	nz	nz	nz	nz

Means ± standard errors marked with different letters within the same column indicate statistically significant differences, as determined by the LSD post hoc test at $p \leq 0.05$. * – significance at $p \leq 0.05$, ns – not significant / *Srednje vrednosti ± standardna greška označene različitim slovnim oznakama u okviru kolone ukazuju na statistički značajne razlike prema testu NZR za $p \leq 0.05$. * - statistički značajno pri $p \leq 0.05$, nz – nije značajno.*



Graph 3. Total soluble solids (TSS) and total acids (TA) content of the raspberry cultivars 'Solu Red' and 'Wakefield' treated with microalgae-based products

Grafikon 3. Sadržaj rastvorljive suve materije (RSM) i ukupnih kiselina (UK) u plodu sorti maline Solu Red i Wakefield tretiranih proizvodima na bazi mikroalgi



Graph 4. The interaction effect of the cultivar and treatment on the total soluble solids (TSS) and total acids (TA) content of 'Solu Red' and 'Wakefield' raspberry cultivars treated with microalgae-based products

Grafikon 4. Interaktivni efekat sorte i tretmana na sadržaj rastvorljive suve materije (RSM) i ukupnih kiselina (UK) u plodu sorti maline Solu Red i Wakefield tretiranih proizvodima na bazi mikroalgi

the cultivar 'Solu Red' under the T_1 treatment, while no significant differences were observed in the cultivar 'Wakefield' (Graph 4). Li et al. (2022) previously reported that biostimulant effectiveness depends on environmental conditions and various cultivars respond differently. Indeed, in our study, TA content varied significantly between the treatments, showing the lowest value in the T_1 treatment in the 'Wakefield' cultivar. Conversely, the highest and similar values for TA were recorded in both biostimulant treatments in the cultivar 'Solu Red'.

Conclusion

To our knowledge, there is still scarce information on the agronomic management of the raspberry cultivars 'Solu Red' and 'Wakefield' in a soilless cultivation system. The evaluation of physiological, agronomic, and fruit quality traits represented the primary goal of better identifying their commercial exploitation. Our findings revealed that the cultivar 'Wakefield' had significantly higher chlorophyll and nitrogen concentration in leaves, as well as TSS in fruits compared to the cultivar 'Solu Red', which showed significantly higher yield potential, fruit size and TA content. The second goal of our study was related to the effect of foliar application of microalgae-based biostimulant treatments ['Algafert' and 'Biofat 600'] in order to better understand cultivar-by-treatment interactions to refine cultivar-specific recommendations. Our field trial showed that both treatments with microalgae-based biostimulants significantly enhanced the leaf concentration of chlorophyll and nitrogen after the second application in both cultivars tested, while the best yield benefits were achieved only in the cultivar 'Solu Red' by spraying once or twice. Additionally, the cultivar 'Solu Red' showed a significant increase in the TSS content in the T_2 treatment, while changes in the TSS were not significant between the treatments in the cultivar 'Wakefield'. Based on these findings, the microalgae-based biostimulants 'Algafert' and 'Biofat 600' can be recommended for combined use in two applications during the spring, especially with the cultivar 'Solu Red' in order to benefit from conjoint nutrient sources in soilless cultivation system.

Acknowledgements

This research was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia through Grant Agreement with the University of Belgrade, Faculty of Agriculture (No. 451-03-137/2025-03/200116). We also thank the R&D team of the company 'Floriva' (Radaljevo, Serbia) for providing new raspberry cultivars and technical support in conducting this experiment.

References

Castiglione A.M., Mannino G., Contartese V., Bertea C.M., Ertani A. (2021): Microbial biostimulants as response to modern agriculture needs: Composition, role and application of these innovative products. Plants, 10: 1533.

Cordeiro E.C.N., Mogor A.F., Amatu J.O., Mogor G., Marque, H.M.C., de Lara G.B. (2022): Microalga biofertilizer improves potato growth and yield, stimulating amino acid metabolism. Journal of Applied Phycology, 34: 385–394.

de Morais M.G., Vaz B.D.S., de Morais E.G., Costa J.A.V. (2015): Biologically active metabolites synthesized by microalgae. Biomed Research International, 2015: 835761.

du Jardin P. (2015): Plant biostimulants: definition, concept, main categories and regulation. Scientia Horticulturae, 196: 3–14.

Ganugi P., Martinelli E., Lucini L. (2021): Microbial biostimulants as a sustainable approach to improve the functional quality in plant-based foods: A review. Current Opinion in Food Science, 41: 217–223.

Handoko R.N.S., Lin S-Y. (2025): Integrating plant growth regulators and biostimulants to enhance resilient and sustainable raspberry and blackberry production. Scientia Horticulturae, 350: 114296.

Haroun S.A., Hussein M.H. (2003): The promotive effect of algal biofertilizers on growth, protein pattern and some metabolic activities of *Lupinus termis* plants grown in siliceous soil. Asian Journal of Plant Science, 2: 944–951.

Li J., Van Gerrewey T., Geelen D. (2022): A meta-analysis of biostimulant yield effectiveness in field trials. Frontiers in Plant Science, 13: 836702.

Kaushal P., Ali N., Saini S., Pati P.K., Pati A.M. (2023): Physiological and molecular insight of microbial biostimulants for sustainable agriculture. Frontiers in Plant Science, 14: 1041413.

Manganaris G.A., Valanides N., Gohari R., Milivojevic J., DeVetter L.W., Fotopoulos V. (2024): Exploring the potential of priming agents towards enhanced performance of Rubus species. Acta Horticulturae, 1388: 7–16.

Mannino G., Bertea C.M., Bonini P. (2022): Editorial: Characterization of biostimulants used in agriculture: A step towards sustainable and safe foods. Frontiers in Plant Science, 13: 1065879.

Milivojević J., Milosavljević D., Radivojević D., Dragišić Maksimović J. (2024): Microalgae-based products as innovative technological approach to enhance performance of soilless

cultivated highbush blueberries. Book of Abstracts of the International Workshop on Soft Fruit Crops, Limassol, Cyprus, p. 32.

Milivojević J. (2022): Posebno voćarstvo 3, Jagodaste voćke. Drugo dopunjeno izdanje. Univerzitet u Beogradu, Poljoprivredni fakultet i AgroNET – Centar za obrazovanje i istraživanja.

Milivojević J., Nikolić M., Radivojević D., Poledica M. (2011): Does harvest time influence fruit quality traits in primocane fruiting raspberry cultivars? Proceedings. 46th Croatian & 6th International Symposium on Agriculture. Opatija, Croatia, pp. 1036–1039.

Morillas-Espana A., Ruiz-Nieto A., Lafarga T., Acien G., Arbib Z., Gonzalez-Lopez C.V. (2022): Biostimulant capacity of *Chlorella and Chlamydopodium* species produced using wastewater and centrate. Biology, 11: 1086.

Park Y.J., Park J.E., Truong T.Q., Koo S.Y., Choi J.H., Kim S.M. (2022): Effect of *Chlorella vulgaris* on the growth and phytochemical contents of "Red Russian" kale (*Brassica napus var. Pabularia*). Agronomy, 12: 2138.

Rouphael Y., Colla G. (2020): Editorial: Biostimulants in agriculture. Frontiers in Plant Science, 11:40.

Spasojević S., Maksimović V., Milosavljević D., Djekić I., Radivojević D., Sredojević A., Milivojević J. (2024): Variation in chemical, textural and sensorial traits among remontant red raspberry (*Rubus idaeus* L.) cultivars maintained in a double-cropping system. Plants, 13: 3382.

Stephens M.J., Enfield R.J., Hall K.H. (2012): 'Wakefield' red raspberry. Hortscience 47(10): 1556–1558.

Stephens M.J., Enfield J. (2012): Progress in the development of raspberry cultivars suited to machine harvest and process markets in the Pacific North West. Acta Horticulturae, 946: 205–210.

Suleiman A.K.A., Lourenco K.S., Clark C., Luz R.L., da Silva G.H.R., Vet L.E., Cantarella H., Fernandez T., Kuramae E.E. (2020): From toilet to agriculture: Fertilization with microalgal biomass from wastewater impacts the soil and rhizosphere active microbiomes, greenhouse gas emissions and plant growth. Resources, Conservation and Recycling, 161: 104924.

Žunić V., Hajnal Jafari T., Stamenov D., Djurić S., Tomić J., Pešaković M., Grohar M.C., Stampar F., Veberic R., Hudina M., Jakopic J. (2024): Application of microalgae based biostimulants in sustainable strawberry production. Journal of Applied Phycology, 36, 1219–1231.

Qiu C., Gaudreau L., Nemati R., Gosselin A., Desjardins Y. (2017): Primocane red raspberry response to fertigation EC, types of substrate and propagation methods. European Journal of Horticultural Science, 82(2): 72–80.

Valentinuzzi F., Pii Y., Mimmo T., Savini G., Curzel S., Cesco S. (2018): Fertilization strategies as a tool to modify the organoleptic properties of raspberry (*Rubus idaeus* L.) fruits. Scientia Horticulture, 240: 205–2012.

BIOSTIMULATORI NA BAZI MIKROALGI MENJAJU FIZIOLOŠKE, AGRONOMSKE I OSOBINE KVALITETA PLODA SORTI MALINE SOLU RED I WAKEFIELD

Jasminka Milivojević[1*], Slavica Spasojević[1], Jovan Radaković[1], Dragan Radivojević[1], Miloš Perišić[2]

[1]*Univerzitet u Beogradu, Poljoprivredni fakultet, Nemanjina 6, 11080 Zemun-Beograd, Republika Srbija*
[*]*E-mail:jasminka@agrif.bg.ac.rs*
[2]*Floriva d.o.o., Radaljevo bb, 32252 Radaljevo, Republika Srbija*

Rezime

Studija ilustruje efekat biostimulatora na bazi mikroalgi Algafert (0,75% N; 7,40% P_2O_5; 3,20% K_2O; 5,60% slobodnih aminokiselina) i Biofat 600 (2,70% N; 6,70% Ca; 0,10% P_2O_5; 0,10% K_2O; 6% slobodnih aminokiselina) na koncentraciju hlorofila (SPAD) i azota (mg g^{-1}) u listu, osobine arhitekture izdanka, produktivnost, biometrijske i hemijske osobine ploda sorti maline Solu Red i Wakefield. Istraživanje je izvedeno na plantaži maline zasađenoj u saksijama (10 l) koje su ispunjene kokosovim tresetom tokom proleća 2022. godine (kompanija Floriva, opština Ivanjica). Primenjeni su sledeći tretmani: T_1 – Biofat 600 (2 folijarne aplikacije, 2 l ha^{-1} po aplikaciji); T_2 – Algafert'(2 folijarne aplikacije, 1 l ha^{-1} po aplikaciji) + Biofat 600 (1 folijarna aplikacija, 2 l ha^{-1}) i T_0 – kontrolni tretman. Prvo folijarno tretiranje izvršeno je 17. maja 2024. godine (40% otvorenih cvetova) i drugo tokom zametanja i rasta plodova. Tretmani biostimulatorima su nakon druge aplikacije značajno povećali koncentraciju hlorofila i azota u listu u poređenju sa kontrolom. Sorta Wakefield je imala značajno veću koncentraciju hlorofila i azota u poređenju sa sortom Solu Red. Sa druge strane, značajno veći broj rodnih prirasta (32,6) i veći prinos po izdanku (1.261,3 g) zabeleženi su kod sorte Solu Red, dok se broj plodova po izdanku nije značajno razlikovao između testiranih sorti. Dobijeni rezultati proučavanja biometrijskih osobina i sadržaja ukupnih kiselina ukazuju na superiornost sorte Solu Red u poređenju sa sortom Wakefield. Ova studija sugeriše da biostimulatori na bazi mikroalgi pružaju jedinstvenu priliku za jačanje kapaciteta biljaka da se nose sa izazovima pojačanim klimatskim promenama.

Ključne reči: Algafert, Biofat 600, malina, hlorofil u listu, prinos, kvalitet ploda