Different Nutrition Approaches for Raspberry (*Rubus idaeus* L.) cv. 'Himbo-Top' (‘Rafzaqu’): Influence on Productivity, Fruit Quality and Storage Potential

Verschiedene Ernährungsansätze für Himbeere (*Rubus idaeus* L.) cv. 'Himbo-Top' ('Rafzaqu'): Einfluss auf Produktivität, Fruchtqualität und Lagerfähigkeit

TATJANA UNUK[1], ŽAN VOGLAR[2], ANDREJ VOGRIN[1] and NINA TOJNKO[1]*

1University of Maribor, Faculty of Agriculture and Life Sciences
Pivola 10, 2311 Hoče, Slovenia
2KGZS Zavod Maribor
Vinarska ulica 14, 2000 Maribor, Slovenia
*E-Mail: nina.tojnko@um.si

Es wurde ein Feldversuch durchgeführt, um die Auswirkungen verschiedener Ansätze der Pflanzenernährung (von extensivem »low-input«- bis hin zu intensivem »Luxus«- Ernährungsprogramm) von Himbeeren (*Rubus idaeus* L.) cv. 'Himbo-Top' (‘Rafzaqu’) hinsichtlich Produktivität, Ertragsqualität und Lagerfähigkeit zu beurteilen. Das Experiment basierte auf der Menge an appliziertem Stickstoff und der Verwendung von Biostimulator mit Zusatz von Silizium (Si). Verschiedene wasserlösliche kristalline Düngemittel wurden in verschiedenen Wachstumsphasen der Pflanzen unter Verwendung eines Düngesystems ausgebracht, während der Biostimulator auf die Blätter aufgebracht wurde. Der Versuch bestand aus vier verschiedenen Behandlungen: 20 kg N/ha insgesamt (in einer Anwendung), 60 kg N/ha insgesamt (kombinierte Anwendungen), 80 kg N/ha insgesamt (kombinierte Anwendungen) und 80 kg N/ha insgesamt (kombinierte Anwendungen) in Kombination mit Biostimulator. Die Ergebnisse zeigen, dass ein höherer Stickstoffgehalt zu einer erhöhten Masse der einzelnen Früchte führt, während dies die Ertragsmenge nicht beeinflusst. Auf einem optimal vorbereiteten Boden mit ca. 3 % organischer Substanz verringert der Einsatz von Stickstoff in einer Menge von mehr als 60 kg N/ha die Fruchtqualität in Bezug auf den Gehalt an löslichen Feststoffen und den sensorischen Wert erheblich. Außerdem wird das Lagerpotential durch erhöhte mikrobielle Aktivität (Schimmelbildung) deutlich reduziert. Die Wirksamkeit des siliziumhaltigen Biostimulators scheint begrenzt zu sein und kann die negativen Auswirkungen höherer Stickstoffmengen auf die Fruchtqualität und Lagerfähigkeit nicht kompensieren.
Schlüsselwörter: Himbeere, Stickstoff, Biostimulator, chemische Zusammensetzung, mikrobielle Aktivität, Geschmack, Silizium

Abstract

A field trial was conducted to assess the effects of different approaches of plant nutrition (from extensive »low-input« to intensive »luxury« nutrition program) of raspberry (*Rubus idaeus* L.) cv. 'Himbo-Top' (‘Rafzaqu’) on productivity, yield quality and storage potential. The experiment was based on the amount of applied nitrogen and the use of a biostimulant with addition of silicon (Si). Different water-soluble crystalline fertilisers were used at different growth stages of the plants with the use of a fertigation system, while the biostimulant was applied on leaves. The experiment consisted of four different treatments: 20 kg N/ha in total in one application, 60 kg N/ha in total in multiple applications, 80 kg N/ha in total in multiple applications and 80 kg N/ha in total in multiple applications in combination with biostimulant. The results show that higher rate of nitrogen results in an increased mass of individual fruit, while it does not affect the total yield. On optimally prepared soil with approx. 3 % of organic matter, the use of nitrogen amounts higher than 60 kg N/ha significantly reduces fruit quality in terms of soluble solids content and sensory value. It also significantly reduces the storage potential due to increased microbial activity (mould appearance). The efficiency of silicon containing biostimulant seems to be limited and cannot compensate the negative effects of higher rates of nitrogen on fruit quality and storability.
Key words: nitrogen, biostimulant, chemical composition, microbial activity, taste, silicon

Introduction

The raspberry is the largest consumer of nutrients among berries. Nutrient requirements depend on crop quantity, habitat, plant age, soil type, irrigation (or precipitation) and cultivar (BOLDA et al. 2012). The highest nitrogen demand is expressed during the period of intense growth, flowering and fruit development (STRIK and BRYLA 2015, KORON et al. 2017). In intensive raspberry plantations, fertigation usually begins at the flower bud stage in June and lasts up until mid-harvest in August, using special water-soluble fertilisers containing P and K as well as various micronutrients (HART et al. 2006, BUSHWAY et al. 2008). The expected response of raspberries to high nitrogen levels is a more vigorous vegetative growth (BUSKIENE and USELIS 2008), larger fruits and consequently increased yield (DALE and DAUBENY 1985), as well as intense flowering (KOWALENKO 1981). The results of several fertiliser trials show some inconsistencies, mainly due to differences in soil fertility, plant age (GERCEKCIOGLU 2008) and also due to duration of the experiment (STRIK 2008).

Effect of nitrogen rates and biostimulants on the quality and storability of raspberries

The storage potential of raspberry fruits is considered to decrease rapidly with storage duration due to its high transpiration rate and fragile structure. In a short time, raspberry fruits lose their firmness, turn darker and begin to mould. Thus the shelf life of raspberries, stored at temperatures of 5 °C, is generally not longer than 4 days, the shortest of all fruit species (HAFFNER et al. 2002, KRÜGER et al. 2011). Problems during short storage are mainly caused by grey mould *(Botrytis cinerea*).
Among the physical characteristics of raspberry fruit that are important indicators of fruit quality, fruit firmness is a parameter that stands out and directly determines the sensitivity to mechanical damage (during harvesting and transport), to potential storage losses and, in particular, infections by pathogens, mostly fungi. According to SJULIN and ROBBINS (1987), a decrease of fruit firmness is directly linked to a severe reduction of the fruit quality.

Fruit quality is also determined by its mineral composition (BUSKIENE and USELIS 2008). Nitrogen overdoses often result in a lower fruit firmness (BUSHWAY et al. 2008) and poor fruit colour since nitrogen is preferably used for rapid growth and to a smaller extent to support secondary metabolism (HARGREAVES et al. 2008). The form of nitrogen also plays an important role, therefore the ammonium form is often used in raspberry production due to its lower effect on growth intensity (VALENTINUZZI et al. 2018b). Some contradictory data can be found in the literature regarding the effect of nitrogen rates on soluble solids content (SS) and titratable acidity (TA) in fruit (PRANGE and DELL 1998). The most common claims are that higher nitrogen rates reduce the soluble solids content of the fruit (STRIK 2008) and increase the TA (STOJANOV et al. 2019), which results in an altered sensory value of the fruit.
According to the many different interpretations that can be found in literature, the most important factor determining the quality and storability of fruit is the genetic background (DALE and DAUBENY 1985). In addition, RIAZ and BUSHWAY (1996) point out the significant influence of weather conditions at the time of harvest, the chemical composition of the fruit, and particularly the difference in temperature between day and night. Thus, biotic and abiotic environmental factors are significant indicators of fruit quality as well as having an impact on storage potential and shelf life (LEPOSAVIĆ et al. 2013). Due to the combinations and overlapping of various genetic factors, weather conditions (temperature, humidity, daily sun radiation, precipitation …) and agro-technical measures in the orchard the determination of the importance of the isolated effect of a single nutrient, such as nitrogen, becomes very demanding.

The use of biostimulants in berry production

Plant biostimulants are compounds that, when applied to plants, seeds or growth substrates, can alter physiological processes, enhance plant and fruit growth and develop as well as influence (mainly improve) the plant's response to stress conditions (HALPERN et al. 2014). Silicon (Si) is also found in some biostimulant formulations but is not recognized as an element, essential for plant growth and development. However, its biostimulating potential has recently been discovered, as it is thought to have a positive effect on the growth and development of many plant species, especially when they are exposed to various biotic and abiotic stressors (SAVVAS and NTATSI 2015).

The use of various biostimulants has been attributed to several additional positive effects: increased fruit weight and fruit firmness (GRAJKOWSKI and OCHMIAN 2007), increased fruit diameter and accelerated ripening (KROK and WIENIARSKA 2008). OCHMIAN et al. (2008) additionally reported about a positive effect of the algae *Ascophyllum nodosum* extract on plant growth, an index of leaf colour intensity and an increased content of anthocyanins in raspberry fruit (28 mg/100 g control and 39 mg/100 g algae). GRAJKOWSKI and OCHMIAN (2007) also pointed out the decrease of soluble solids (hereafter SS) content compared to the control (-0.7 °Brix), while the effect of biostimulants on the titratable acids (hereafter TA) was not confirmed. Some authors (MA 2004, SAVVAS and NTATSI 2015) have also reported positive effects of silicon on the control of a wide range of diseases and pests of fungal and bacterial origin in different plant species (vegetables, ornamentals, fruit plants, field crops…). These positive effects are attributed to the accumulation of silicates in the surface tissues, which improves the mechanical resistance and regulates the mobility of water and nutrients in the tissues. HAJIBOLAND et al. (2017) state that silicon does not only show positive effects under stress but also under optimal growing conditions. According to SAVVAS and NTATSI (2015), mainly ground applications of silicates are expected to be effective.

The main goal of the presented study was to define the effects of different fertigation approaches to raspberry nutrition as well as to clarify the role of nitrogen rate (20, 60 and 80 N kg/ha) and the use of a selected algae-based biostimulant with added Si on fertility, yield characteristics and storability.

Materials and methods

The experimental raspberry orchard was located in north-eastern Slovenia. The average altitude of the plantation is 272 m with a 10 % gradient and the total orchard area was 1.18 ha. The orchard was established in 2014. The variety used in the trial was 'Himbo-Top' (‘Rafzaqu’), highly resistant to *Phytophtora fragariae* (UNITED STATES PATENT AND TRADEMARK OFFICE 2008). In the year of the experiment the raspberry plants were on average 5 years old. The planting distance was 3 x 0.5 m (app. 6666 plants/ha). The strips between the rows were grassed, and the strips under the plants were mown. The orchard was included in the Global G.A.P. certification scheme. It was designed as a wide single-row system and equipped with a two-line irrigation system. Pruning was carried out in winter (all shoots cut to the ground). The production technology was adapted to a single harvesting period. Thinning of the shoots was carried out in spring and the maximum number of shoots was 11 per meter. The plants were protected with anti-hail net and plastic greenhouse foil. The foil was removed at the beginning of blooming.

Climatic conditions at the time of the experiment

The experimental year 2019 was the second warmest year since 1961. The average annual temperature in Maribor in 2019 was 11.9 °C, with 972 mm of precipitation. There were 2116 sunshine hours which is 6 % above the long-term average. The year of the experiment was marked by some weather extremes (ARSO 2020):

- May: intensive precipitations along with low average temperatures;
- June: unusually warm and dry weather with an exceptionally high number of sunshine hours;
- July: intensive precipitations and high average summer temperatures;
- Four prolonged heatwaves in summer (Table 1).

Table 1: Average monthly air temperature and precipitation during the experiment period, Vitomarci agrometeorological station (year 2019)

Parameter	**Month**				
	May	**June**	**July**	**August**	**September**
Temperature (°C)	12.4	22.4	21.3	21.6	16.1
Precipitation (mm)	208.6	58	89.8	42.2	77.6

Soil in the orchard

Soil in the plantation belongs to the eutric cambisol category. The organic matter content was 2.99 %, and the pH 6.55. The data in Table 2 show that before the trial the soil in the experimental plantation was well supplied with phosphorus (class C), while the potassium load was measured to fit in class B (Table 2).

Table 2: Soil analysis in the raspberry orchard at the beginning of the experiment

Measurement	**Value**	**Class**
Potassium K_2O (available) (mg/100 g sample)	17.51	B
Phosphorus P_2O_5 (available) (mg/100 g sample)	17.80	C
Humus (%)	2.99	
pH value	6.65	

Experiment design

The experiment was set up as a randomized block design and consisted of 4 treatments in 4 replications. Each replication consisted of 7 plants, similar in vegetative and generative development. Treatment designation is based on total N rate and use of biostimulant. Source of N was derived from different fertilisers and applied at different growth stages (table 3) with the use of the irrigation system. The experiment consisted of the following treatments:

1. Control treatment (hereafter referred to as C; basic fertilization with pelleted farmyard manure with final rate of pure N up to 20 kg/ha; no fertigation, the so-called "extensive" or "low-input" approach).
2. Additional fertigation with 40 kg N/ha (hereafter referred to as treatment 60 kg N/ha; basic fertilization with 20 kg N/ha + 40 kg N/ha via fertigation).
3. Additional fertigation with 60 kg N/ha (hereafter referred to as treatment 80 kg N/ha; basic fertilization with 20 kg N/ha + 60 kg N/ha via fertigation).
4. Additional fertigation with 60 kg N/ha + use of biostimulant (hereafter referred to as treatment 80 kg N/ha + BS; basic fertilization 20 kg N/ha + 60 kg N/ha via fertigation + addition of a seaweed-based biostimulant with added silicon via foliar application; the so-called "luxury nutrition").

In all treatments the basic fertilization was carried out in spring (Table 3). Manure pellets were applied in an amount of 1 T/ha (20 kg N/ha) in the inter-row space. In the 60 kg N/ha, 80 kg N/ha and 80 kg N/ha + BS treatments, nitrogen addition up to the target rate was carried out by fertirrigation with the use of water-soluble NPK-type fertilisers in crystalline formulations (with use of 11 L of water per meter). In the 80 kg N/ha + BS treatment, the biostimulant was applied on leaves at the amount prescribed by the manufacturer.

Table 3: Fertilisation/fertigation program and dynamics in relation to development stage of raspberry plants (BBCH: Biologische Bundesanstalt und Chemische Industrie; BS: biostimulant; N: nitrogen)

Growth phase/period	**Fertiliser/measure**	**Fertiliser rates**	**Treatment**
Dormant period (BBCH 00)	Pelletized manure	1 T/ha (20 kg N/ha or 3 g/plant);	All treatments
Initiation of growth, flower bud development (BBCH 51-59)	Fertiliser A (Solinure®)	25 kg/ha/week (3,17 g/plant);	60 kg N/ha
		37,5 kg/ha/week (5,62 g/plant);	80 kg N/ha, 80 kg N/ha + BS
Flowering, fruit formation, ripening (BBCH 61-79)	Fertiliser B (Hakaphos Violeta®)	25 kg/ha/week (3,75 g/ plant);	60 kg N/ha
		37,5 kg/ha/week (5,62 g/plant);	80 kg N/ha, 80 kg N/ha + BS
Harvesting period (BBCH 81-89)	Fertiliser C (NovaTec® Solub)	25 kg/ha/week (3,75 g/ plant);	60 kg N/ha
		37,5 kg/ha/week (5,62 g/plant)	80 kg N/ha, 80 kg N/ha + BS
4 times during the growing season (BBCH 51-89)	Biostimulant (Vitanica® Si)	8,75 ml/28 plants (0.31 mL/plant) - 2.08 l/ha	80 kg N/ha + BS

In the experiment, different fertilisers were applied at 3 different stages of raspberry development. The fertilisers used had the following composition:

- Pelletized manure: from an unknown producer, containing 2 % nitrogen with a C/N ratio of 24.
- Fertiliser A (Solinure® (Everris International, Netherlands)): 20 % total nitrogen, 20 % phosphorus (P_2O_5), 20 % potassium (K_2O), iron (0,06 %), manganese (0,05 %), boron (0,01 %), copper (0,01 %), molybdenum (0,005 %) and zinc (0,022 %).
- Fertiliser B (Hakaphos Violeta® (COMPO EXPERT GmbH, Münster, Germany)): 13 % nitrogen, 40 % phosphorus and 13 % potassium, iron (0,05 %), copper (0,01 %), zinc (0,01 %), magnesium (0,11 %) and manganese (0,05 %).
- Fertiliser C (NovaTec® Solub (COMPO EXPERT GmbH, Münster, Germany)): 14 % nitrogen, 8 % phosphorus and 30 % potassium, sulphur (5,6 %) and magnesium (0,7 %).
- Biostimulant (BS) (Vitanica® Si (COMPO EXPERT Italia, Cesano Maderno, Italy)): 5 % nitrogen, 3 % phosphorus, 7 % potassium, 1.7 % sodium, 10 % silicon, 22.7 % organic matter and an extract of the seaweed *Ecklonia maxima* (Table 3).

Sampling and quality determination

The harvesting season lasted 6 weeks (25th July 2019 to 30th August 2019). During this time, eight harvests were carried out. During and after harvesting, measurements of selected yield and quality parameters were performed (weight of the yield per plant, weight of 10 fruits; use of the Kern 442-43-N scale (Kern®, Germany). Harvested fruit was immediately stored at low temperature (“fridge van”, normal atmosphere, 5 °C). Fruit sampling for the assessment of chemical composition and storability was carried out during the period of full bearing (August 5, August 10 and August 12).

Standard analysis of internal fruit quality parameters (SS content - refractometric value expressed in °Brix and TA value - titratable acid expressed in (g/L)) were carried out with a sample of 15 fruits immediately after harvesting. Fruit taste was determined with the Thiault index (SS/TA*10) (VARELA et al. 2005).

For the assessment of the storability fruits were kept in a cold storage with a normal atmosphere (NA) at 5 °C. Changes in the weight and volume were monitored daily. Volume changes were monitored using a piece of cardboard placed on the fruit in each container (plastic containers with 250 g of fruit); the level to which the cardboard lowered in the container while fruit collapsed under it served as an indicator of fruit volume decrease. Changes in mass and volume were expressed in percentages. After 7 days of storage, the incidence of mould was assessed visually and expressed as percentage of infected fruits.

Statistical processing of data

The data analyses were performed using Statgraphics Centurion (version 15.2). The differences between treatments were determined using a one-way analysis of variance (ANOVA) ($p < 0.05$). Further analysis of data was performed by Duncan’s MRT pairwise comparison test at $p < 0.05$.

Results and discussion

The approach of plant nutrition, the nitrogen rate and the use of the biostimulant had no significant effect on raspberry yield. The yield varied between 61.11 g/plant and 72.37 g/plant (Table 4). However, the so-called 'luxury nutrition' (80 kg N/ha and/or 80 kg N/ha + BS), significantly increased the weight of individual fruits (from app. 3.5 g/fruit to app. 3.85 g/fruit) compared to the control and 60 kg N/ha treatment (approx. up to 11 %), but no additional effect of BS on average fruit weight (in combinations with high nitrogen rates) was confirmed (Table 4).

Table 4: Effect of nutrition regime on yield characteristics in raspberry cultivar 'Himbo -Top' (average values for one harvest period and cumulative values) (N: nitrogen, BS: biostimulant). Effect of nutrition approach is evident from the line "Nutrition program information", effect of nitrogen rate is evident from the first three values in the line "N-rate" and effect of used biostimulant is evident from the last two values in the line "BS". Different letters (in the individual line) mean statistically significant differences according to the Duncan's MRT test (α < 0.05).

Treatment: → **Parameter:↓**		**Control** **(20 kg N/ha)**	**60 kg N/ha**	**80 kg N/ha**	**80 kg N/ha + BS**
Yield (g/plant; average of all harvest periods)		61.11±10.91	64.83±11.25	71.30±18.85	72.37±18.82
Impact of:	Nutrition program	ns	ns	ns	ns
	N-rate	ns	ns	ns	/
	BS	/	/	ns	ns
Weight of 1 fruit (g; average of all harvest periods)		3.46±0.09	3.58±0.10	3.85±0.15	3.86±0.14
Impact of:	Nutrition program	b	b	a	a
	N-rate	b	b	a	/
	BS	/	/	ns	ns
Yield weight (g/plant) (cumulative for all harvest periods)		916.65±163.65	972.45±168.75	1069.5±282.65	1085.5±282.14
Impact of:	Nutrition program	ns	ns	ns	ns
	N-rate	ns	ns	ns	/
	BS	/	/	ns	ns

Data in the literature for 'Himbo-Top' variety average fruit mass varies widely, ranging from 1.9 g (MILIVOJEVIĆ et al., 2011) to 5.16 g (ANDRIANJAKA - CAMPS et al., 2016). These differences are most likely due to different technological measures, plant age and a negative correlation with yield.

The results of presented experiment are in accordance with HEIBERG (2002) who also reports about a non-significant increase in yield with increasing nitrogen rates (40 kg/ha, 133 kg/ha and 178 kg/ha were used in the experiment) and a significant increase in the average weight of the individual fruits. A non-significant effect of nitrogen rate on yield and a confirmed positive effect on average fruit weight have also been reported by KOWALENKO (1981), BUSKIENE and USELIS (2008), HEIBERG (2002) and GERCEKCIOGLU (2008). KOWALENKO (2006) and STRIK (2008) identified soil nutrient supply as the main reason for the relatively poor response of plants to higher nitrogen rates, in the sense that "the better the nutrient supply of the soil, the smaller the generative response of the plant to higher nitrogen rates".

In some studies, authors have described significant yield increases after the use of biostimulants (OCHMIAN et al., 2008), with the increase of yield of up to 1.8 T/ha compared to the control (app. + 13.6 %); also KROK and WIENIARSKA (2008) reported a higher weight of raspberry fruit (+4 %) treated with biostimulants. However, the same authors highlight the inconsistent effect of biostimulants on fruit weight, which can be largely dependent on the growing season and variety. While VALENTINUZZI et al. (2018a) report that the growers can expect a positive effect of silicon application when they grow raspberries in potted plants and in controlled conditions (tunnels), in the case of raspberries planted in the soil and without fixed tunnels, the effect of foliar application of silicon-containing biostimulant on fruit weight increase or yield increase was not confirmed.

Parameters of internal quality of the fruit

Table 5 shows the average SS and TA content, as well as the values of Thiault index, of the fruit sampled during the intensive ripening period. The SS content of the fruit ranged between 6.43 °Brix and 7.1°Brix depending on the nutrition program (nutrition approach). It showed a negative correlation to higher nitrogen rates, already visible when the rate of nitrogen was increased to 60 kg N/ha. The effect of the BS used on SS content was not confirmed (Table 5). In presented experiment, SS content of 'Himbo-Top' variety was about 40 % lower than expected, since GIUGGIOLIA et al. (2015), MILIVOJEVIĆ et al. (2011), PEANO et al. (2013) reported values between 9,5 °Brix and 11 °Brix.

There was no significant effect of nutrition approach on TA content. TA values varied from 11.7 g/L in the control to 13.08 g/L in the most heavily fertilised raspberries (Table 5). Based on information in the literature, the average TA levels in fruits for the cultivar 'Himbo-Top' range from 9.6 g/L (MILIVOJEVIĆ et al., 2011) to a very high 15.6 g/L (GIUGGIOLIA et al., 2015), while PEANO et al. (2013) recorded values comparable to the ones in our experiment.

Table 5**:** Impact of treatment on soluble solids content, titratable acids and sweetness index (SSC: soluble solids content, TA: titratable acids; N: nitrogen, BS: biostimulant). Effect of nutrition approach is evident from the line "Nutrition program", effect of nitrogen rate is evident from the first three values in the line "N-rate", effect of used biostimulant is evident form the last two values in the line "BS". Different letters (in the individual line) mean statistically significant differences according to the Duncan's MRT test (α < 0.05).

Treatment: → **Parameter:↓**		**Control** **(20 kg N/ha)**	**60 kg N/ha**	**80 kg N/ha**	**80 kg N/ha + BS**
Soluble solids (°Brix)		7.1±0.24	6.48±0.18	6.65±0.19	6.43±0.25
Impact of:	Nutrition program	a	b	b	b
	N-rate	a	b	ab	/
	BS	/	/	ns	ns
Titratable acids (g/L)		11.71±1.00	12.43±0.77	12.68±0.78	13.08±1.08
Impact of:	Nutrition program	ns	ns	ns	ns
	N-rate	ns	ns	ns	
	BS			ns	ns
Thiault index		6.10±0.34	5.21±0.54	5.24±0.53	4.96±0.39
Impact of:	Nutrition program	a	ab	ab	b
	N-rate	a	b	b	/
	BS	/	/	ns	ns

The differences between the treatments (nutrition approach) were more pronounced in the Thiault index, a widely accepted parameter in practice that determines flavour, which is particularly important in terms of consumer acceptability (MAZUR et al., 2014). According to DROBEK et al. (2019), the quality of raspberry fruit is considered good if the ratio of SS to TA varies between 10 and 15, while KADER (1999) recommends a ratio of 10.

In the presented experiment it ranged between 4.96 and 6.10 and was relatively low (Table 5). It was influenced by the amount of nitrogen, in the way that intensifying nitrogen fertilization (increasing the nitrogen rate above 20 kg N/ha) significantly impaired the flavour of raspberries, so “the more "luxurious" the nutrition, the worse the flavour”. The use of BS, combined with higher N rates, could not compensate negative effects of high N dosages on organoleptic properties of fruits.

Storage potential of the raspberries

Table 6 shows the results in which 3 standard parameters of fruit storage potential were monitored: reduction in fruit weight and volume along with the occurrence of storage diseases. Loss of weight during storage is a factor that significantly reduces a fruit’s market value, mainly due to transpiration losses. In addition to temperature and relative humidity, it is influenced by the degree of fruit ripeness at the time of harvest and the variety of fruit.

After 7 days of storage at 5 °C, no significant effect of the nitrogen dose on storage parameters such as weight and volume loss was confirmed, nor were these parameters affected by the BS. The percentage of fruit weight loss ranged from 3.22 % to 3.54 %, and the percentage of volume loss ranged from 16.78 % to 22.67 %.

According to the results of presented study we cannot confirm the claim of VALENTINUZZI et al. (2018a) that the use of BS improves the quality of fruits in the period of harvest and prevents a significant weight loss during storage. NUNES and ÉMOND (2003) stated that the maximum weight loss of fruit, before it loses its market value, is 6 %.

The decision on the approach of plan nutrition seems to be important mainly regarding the occurrence of storage diseases of fruits, for the most part influenced by the evaluation of the activity of the fungus Botrytis c. After 7 days of storage, the percentage of mouldy fruit in cold storage ranged from 57.12 % to 75.61 %, so “the more "luxurious" the nutrition (higher nitrogen doses), the more pronounced was fungal activity”.

The severe decline in the storage capability of raspberries, linked to the application of high nitrogen rates, was also highlighted by ALI (2012) and ALI et al. (2012). The use of the chosen BS (foliar application) in our experiment did not play a significant role in preventing fruit collapse in cold storage under the given conditions, neither in terms of preventing physiological collapse nor in terms of preventing the occurrence of storage diseases, even though raspberries were exposed to a number of abiotic stresses during the growing season (4 heat waves, extremely high number of sunshine hours, etc.). So, the effect of the algae and silica-based biostimulant (in combination with higher doses of nitrogen) on fruit set and fruit quality remained unconfirmed. The results therefore do not support the thesis of HAJIBOLAND et al. (2017), who point out that silicon shows positive effects on quality under stress and under optimal growing conditions. The reason could partially originate from the application practice; according to SAVVAS and NTATSI (2015) foliar application of silicates seems to be less effective than application through the root system when it comes to reducing the negative effects of abiotic stress factors.

The so called 'luxury' raspberry nutrition (80 kg N/ha or 80 kg N/ha + BS) did not prove to be advantageous in terms of raspberry quality, yield and storability. On the contrary, raising the nitrogen rate above 60 kg N/ha in an orchard with optimal soil preparation and high organic matter content (approx. 3%) proved to be an inappropriate technological decision, with no effect on yield and with a clear negative effect on storage capability as well as sensory parameters of raspberries. That negative effect could not be compensated by the use of algae- and silica-based biostimulant.

Table 6**:** Effect of treatment (nutrition program) on the storability of raspberries (change in fruit weight and volume and microbiological activity - occurrence of moulds) after storage at 5 °C for 7 days). Effect of nutrition approach is evident from the line “Nutrition program”, effect of nitrogen rate is evident from the first three values in the line “N-rate”, effect of used biostimulant is evident form the last two values in the line “BS”. Different letters (in the individual line) mean statistically significant differences according to the Duncan’s MRT test (α < 0.05).

Treatment: → **Parameter:↓**		**Control**	**60 kg N/ha**	**80 kg N/ha**	**80 kg N/ha + BS**
Mass reduction (%)		3.22±0.34	3.27±0.35	3.51±0.49	3.54±0.34
Impact of:	Nutrition program	ns	ns	ns	ns
	N-rate	ns	ns	ns	/
	BS	/	/	ns	ns
Volume reduction (%)		16.78±7.64	22.08±13.37	17.03±8.4	22.67±9.39
Impact of:	Nutrition program	ns	ns	ns	ns
	N-rate	ns	ns	ns	/
	BS	/	/	ns	ns
Incidence of mould (%)		57.12±4.37	68.07±5.31	69.65±6.61	75.61±7.55
Impact of:	Nutrition program	b	ab	ab	a
	N-rate	b	a	a	/
	BS	/	/	ns	ns

References

Ali, L. 2012: Pre-Harvest Factors Affecting Quality and Shelf-Life in Raspberries and Blackberries (*Rubus* Spp. L.) (PhD dissertation). Swedish University of Agricultural Sciences, Alnarp. Available at: https://pub.epsilon.slu.se/9029/

Ali, L., Alsanius, B. W., Svensson, B., Nielsen T., Olsson, M. E. 2012: Effects of nutrition strategy on the levels of nutrients and bioactive compounds in blackberries. European Food Research and Technology volume 234: 33–44.

Andrianjaka - Camps, Z. N., Wittemann, M. S., Ançay, A., Carlen, C. 2016: New cultivars for quality production of primocane fruiting raspberries enriched in healthy compounds. *Acta Horticulturae, 1133:* 345−353.

ARSO VREME 2020: Podnebne razmere leta 2019. [Digital source]. Available at: https://meteo.arso.gov.si/uploads/probase/www/climate/text/sl/weather_events/podnebne-razmere-leta-2019.pdf [15. 3. 2020].

Bolda, M., Gaskell, M., Mitcham, E., Cahn, M. 2012: *Fresh market caneberry production manual*. Richmond, California: University of California Agriculture and Natural resources. Publication 3525.

Bushway, L., Pritts, M., Handley, D. 2008: *Raspberry & blackberry production guide for northeast, midwest and eastern Canada*. Ithaca, New York: Plant and Life Sciences Publishing (PALS) Cooperative Extension. Available at https://ecommons.cornell.edu/handle/1813/66930 [22. 2. 2020].

Buskiene, L., Uselis, N. 2008: The influence of nitrogen and potassium fertilizers on the growth and yield of raspberries cv. "Polana". *Agronomy Research, 6(1):* 27–35. Available at: https://pdfs.semanticscholar.org/0ba6/c9e39c0f3a50eea22ac67968da6779d5e9f0.pdf [23. 2. 2020].

Dale, A., Daubeny, H. A. 1985: Genotype–environment interactions involving British and Pacific Northwest red raspberry cultivars. *HortScience, 20*: 68−69.

Drobek, M., Frąc, M., Cybulska, J. 2019: Plant Biostimulants: Importance of the Quality and Yield of Horticultural Crops and the Improvement of Plant Tolerance to Abiotic Stress—A Review. *Agronomy, 9(6)*: 1–18. Available at: https://doi.org/10.3390/agronomy9060335

Gercekcioglu, R. 2008: Cane Characteristics of ‘Cola II’ Red Raspberry as Affected by Application of Nitrogen Fertilizers and Organic Manure. *Journal of Applied Biological Sciences, 2(1)*: 81−83. Available at https://dergipark.org.tr/en/download/article-file/414972 [7 Feb 2020].

Giuggiolia, N. R., Brianoa, R., Baudinob, C., Peanoa, C. 2015: Effects of packaging and storage conditions on quality and volatile compounds of raspberry fruits. *Journal of Food, 13(4)*: 1−10. Available at https://doi.org/10.1080/19476337.2015.1011238

Grajkowski, J., Ochmian, I. 2007: Influence of three biostimulants on yielding and fruit quality of three primocane raspberry cultivars. *Acta Scientiarum Polonorum Hortorum Cultus, 6(2)*: 29–36. Available at http://www.hortorumcultus.actapol.net/pub/6_2_29.pdf [4 Mar 2020].

Haffner, K., Rosenfeld, H. J., Skrede, G., Wang, L. 2002: Quality of red raspberry *Rubus idaeus* L. cultivars after storage in controlled and normal atmospheres. *Postharvest Biology and Technology, 24(3)*: 279−289.

Heiberg, N. 2002. Effect of vegetation control and nitrogen fertilization in red raspberry. *Acta Horticulturae, 585*: 579–583.

Hajiboland, R., Moradtalab, N., Eshaghi, Z., Feizy, J. 2017: Effect of silicon supplementation on growth and metabolism of strawberry plants at three developmental stages. *New Zealand Journal of Crop and*

Horticultural Science, 46(2): 1–19. Available at https://doi.org/10.1080/01140671.2017.1373680

Halpern, M., Bar-Tal, A., Ofek, M., Minz, D., Muller, T.,Yermiyahu, U. 2014: The Use of Biostimulants for Enhancing Nutrient Uptake. *Advances in Agronomy, 130*: 141−174.

Hargreaves, J., Sina Adi, M., Warman, P. R., Vasantha Rupasinghe, H. P. 2008: The effects of organic amendments on mineral element uptake and fruit quality of raspberries. *Plant Soil, 308*: 213−226.

Hart, J., Strik, B. C., Rempel, H. 2006: *Caneberries - Nutrient management guide*. Oregon State University Extension Service. Available at https://catalog.extension.oregonstate.edu/em8903 [3 Mar 2020].

Kader, A. A. 1999: Fruit maturity, ripening, and quality relationships. *Acta Horticulturae, 485*: 203−208.

Koron, D., Munda, A., Modic, Š., Poje, T., Leskovšek, R., Vončina, A., Urek, G. 2017: Smernice integriranega varstva maline. Kmetijski inštitut Slovenije. 7–9. Available at https://www.ivr.si/wp-content/uploads/2018/12/Smernice-IVR-maline_revi2018.pdf [3 Mar 2020].

Kowalenko, C. G. 1981: Response of raspberries to soil nitrogen and boron applications. *Communications in Soil Science and Plant Analysis, 12(11)*: 1151−1162. Available at https://doi.org/10.1080/00103628109367225

Kowalenko, C. G. 2006: The effect of nitrogen and boron fertilizer applications on Willamette red raspberry growth, and on applied and other nutrients in the plant and soil over two growing seasons. *Canadian Journal of Plant Science, 86(1)*: 213−225. Available at https://www.nrcresearchpress.com/doi/abs/10.4141/P04-036 [6 Feb 2020].

Krok, K., Wieniarska, J. 2008: Effect of Göemar BM 86 application on development and quality of primocane raspberry fruits. In Z. T. Dabrowski (Ed.), *Biostimulators in modern agriculture, Fruit crops* (pp. 49–60). Warsaw: Editorial House Wies Jutra. Available at http://www.atonik.pl/bio/FRUIT%20CROPS.pdf#page=50 [23 Feb 2020].

Krüger, E., Dietrich, H., Schöpplein, E., Rasim, S., Kürbel, P. 2011: Cultivar, storage conditions and ripening effects on physical and chemical qualities of raspberry fruit. *Postharvest Biology and Technology, 60(1)*: 31−37.

Leposavić, A., Janković, M., Đurović, D., Veljković, B., Keserović, Z., Popović, B., Mitrović, O. 2013: Fruit quality of red raspberry cultivars and selections grown in Western Serbia. *HortScience, 40(4)*: 154−161. Available at https://doi.org/10.17221/267/2012-HORTSCI

Ma, J. F. 2004: Role of Silicon in Enhancing the Resistance of Plants to Biotic and Abiotic Stresses. *Soil Science and Plant Nutrition, 50(1)*: 11−18. Available at https://doi.org/10.1080/00380768.2004.10408447

Mazur, S. P., Sønsteby, A., Wold, A. B., Foito, A., Freitag, S., Verrall, S., Conner, S., Stewart, D., Heide, O. M. 2014: Post-flowering photoperiod has marked effects on fruit chemical composition in red raspberry (*Rubus idaeus*). *Annals of Applied Biology, 165(3)*: 454−465.

Milivojević, J., Radivojević, D., Dragišić Maksimović, J. 2011: Generative and fruit quality characteristics of primocane fruiting red raspberry cultivars. *Turkish Journal of Agriculture and Forestry, 35*: 289−296. Available at https://doi.org/10.3906/tar-1001-617

Nunes, M. C., ÉMOND, J. 2003: Predicting Shelf Life and Quality of Raspberries Under Different Storage Temperatures. *Acta Horticulturae, 683*: 599−607.

Ochmian, I., Grajkowski, J., Skupie, K. 2008: Influence of three biostimulators on growth, yield and fruit chemical composition of "Polka" raspberry. In Z. T. Dabrowski (Ed.), *Biosimulators in Modern Agriculture, Fruit Crops* (pp. 68–76). Warsaw: Editorial House Wies Jutra. Available at http://www.atonik.pl/bio/FRUIT%20CROPS.pdf#page=50 [23 Feb 2020].

Peano, C., Girgenti, V., Palma, A., Fontanella, E., Giuggioli, N. R. 2013: FILM TYPE AND MAP ON CV. HIMBO TOP RASPBERRY FRUIT QUALITY, COMPOSITION AND VOLATILES. *Italian Journal of Food Science, 25*: 421−431. Available at http://www.chiriottieditori.it/pdf/ijfs/IJFS%20254%20ok.pdf#page=46 [20 Mar 2020].

Prange, R. K., Dell, J. R. 1998: Preharvest Factors Affecting Postharvest Quality of Berry Crops. *HortScience, 32(5)*: 824−831. Available at https://www.researchgate.net/profile/Robert_Prange/publication/279651239_Preharvest_Factors_Affecting_Postharvest_Quality_of_Berry_Crops/links/578682dc08ae36ad40a69586.pdf [8 Feb 2020].

Riaz, M. N., Bushway, A. 1996: Compositional analysis of four red raspberry cultivars grown in Main. *Journal of Food Quality, 19(6)*: 457−465. Available at https://doi.org/10.1111/j.1745-4557.1996.tb00441.x

Savvas, D., Ntatsi, G. 2015: Biostimulant activity of silicon in horticulture. *Scientia Horticulturae, 196*: 66−81.

Sjulin, T. M., Robbins, J. A. 1987: Effects of maturity, harvest date, and storage time on postharvest quality of red raspberry fruit. *Journal of the American Society for Horticultural Science, 112(3)*: 481−487.

Stojanov, D., Milošević, T., Mašković, P., Milošević, N., Glišić, I., Paunović, G. 2019: Influence of organic, organo-mineral and mineral fertilizers on cane traits, productivity and berry quality of red raspberry (*Rubus idaeus* L.). *Scientia Horticulturae, 252*: 370−378.

Strik, B. 2008: A review of nitrogen nutrition of *Rubus*. In Bañados, P., Dale, A. (Ed.), *Proceedings of the IXth International Rubus and Ribes Symposium* (pp. 403–410). Pucon, Chile: Acta Horticulturae, 777.

Strik, B. C., Bryla, D. R. 2015: Uptake and Partitioning of Nutrients in Blackberry and Raspberry and Evaluating Plant Nutrient Status for Accurate Assessment of Fertilizer Requirement. *HortTechnology, 25(4)*: 452−459. Available at https://doi.org/10.21273/HORTTECH.25.4.452

UNITED STATES PATENT AND TRADEMARK OFFICE. 2008: *Variety of Raspberry plant named 'Rafzaqu'*. [Electronic resource]. Available at https://patents.google.com/patent/USPP19512P3/en [17 Mar 2020].

Valentinuzzi, F., Cologna, K., Pii, Y., Mimmo, T., Cesco, S. 2018a: Assessment of silicon biofortification and its effect on the content of bioactive compounds in strawberry (Fragaria × ananassa 'Elsanta') fruits. *Acta Horticulturae, 1217*: 307−313.

Valentinuzzi, F., Youri, P., Mimmoa, T., Savini, G., Curzel, S., Cesco, S. 2018b: Fertilization strategies as a tool to modify the organoleptic properties of raspberry (*Rubus idaeus* L.). *Scientia Horticulturae, 240*: 205−212.

Varela, P., Salvador, S., Fiszman, S. 2005: Shelf-life estimation of 'Fuji' apples: Sensory characteristics and consumer acceptability, Postharvest Biology and Technology, Volume 38, Issue 1. 18–24.