agronomy

MDPI

Article

The Effect of the Foliar Application of Biostimulants in a Strawberry Field Plantation on the Yield and Quality of Fruit, and on the Content of Health-Beneficial Substances

Piotr Zydlik [1,*], Zofia Zydlik [2] and Nesibe Ebru Kafkas [3,*]

[1] Department of Entomology and Environment Protection, Faculty of Agronomy Horticulture and Biotechnology, Poznań University of Life Sciences, 60-637 Poznan, Poland
[2] Department of Ornamental Plant, Dendrology and Pomology, Faculty of Agronomy, Horticulture and Biotechnology, Poznań University of Life Sciences, 60-637 Poznan, Poland; zofia.zydlik@up.poznan.pl
[3] Department of Horticulture, Faculty of Agriculture, University of Çukurova, 01330 Sarıçam, Adana, Turkey
* Correspondence: piotr.zydlik@up.poznan.pl (P.Z.); ebruyasakafkas@gmail.com (N.E.K.)

Abstract: In modern horticulture, biostimulants can be an effective alternative to traditional, industrial means of production. The aim of the study was to assess the effect of three biostimulants (Calgreen, Erathis, Greit VG) containing selected macronutrients (N, Ca), organic matter, and amino acids on the yield and quality of strawberries and their content of health-beneficial substances. In the comparative variant, the plants were treated with mineral fertilisers applied into the soil. In 2021, an experiment was conducted on a two-year-old strawberry plantation of the 'Rumba' cultivar located on a horticultural farm in northwestern Poland. The following parameters were assessed: the yield, weight, and firmness of fruits as well as their content of soluble substances, sugars, organic acids, phenolic compounds, and anthocyanins. The use of biostimulants caused a decrease in soil acidity and salinity. In comparison with the soil fertilisation variant, the number of flowers and fruits on the plants increased by 50% to over 100%, which translated into a significant increase in the yield. The fruits from the plants treated with the biostimulants several times were of better quality. Their average weight, firmness, and the content of soluble substances (also after being stored for several days) increased significantly. However, the total content of sugars and ascorbic and malic acids, as well as the content of phenolic compounds and anthocyanins, did not change.

Keywords: biostimulants; strawberry; fruit quality; sugars; organic acids; phenolic compounds

check for updates

Citation: Zydlik, P.; Zydlik, Z.; Kafkas, N.E. The Effect of the Foliar Application of Biostimulants in a Strawberry Field Plantation on the Yield and Quality of Fruit, and on the Content of Health-Beneficial Substances. *Agronomy* **2024**, *14*, 1786. https://doi.org/10.3390/agronomy14081786

Academic Editor: Spyridon A. Petropoulos

Received: 10 July 2024
Revised: 8 August 2024
Accepted: 12 August 2024
Published: 14 August 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Strawberries are some of the most commonly produced and consumed soft fruits. They look attractive, have a unique taste, and their consumption is beneficial to health. The health-promoting properties of strawberries result from the presence of phenolic compounds and anthocyanins, which have anticancer properties [1] and prevent cardiovascular diseases [2,3]. Strawberries have a relatively low energy value and are rich in B vitamins, polyphenolic compounds, and easily digestible organic compounds [4]. Apart from phenolic compounds and anthocyanins, another natural antioxidant found in strawberries is vitamin C, whose content ranges from 50 mg to about 80 mg [5] in 100 g of fresh fruit. It is even several times greater than the content of vitamin C in apples or grapes [6].

Poland is a major producer of strawberries. According to the Central Statistical Office (GUS), in 2023, about 180,000 tonnes of strawberries were harvested from plantations occupying an area of about 30,000 ha. This volume of production makes Poland the second (or third, depending on the year) largest producer of strawberries in Europe.

Agricultural production is profitable if the yield of crops is high. The yield can be increased by using efficient and attractive cultivars and/or applying appropriate cultivation practices based on conventional production methods such as mineral fertilisation to supplement nutrient deficiencies. This type of fertilisation has numerous advantages. It enables a

relatively quick and effective supply of nutrients (especially macronutrients) to the soil [7]. This ensures mass production of plants, which is particularly important in view of the increasing number of consumers around the world. However, long-term intensive mineral fertilisation, especially with nitrogen fertilisers, may have negative influence on natural ecosystems or reduce soil fertility [8] due to a decrease in the content of humic acids [9], an increase in soil acidity [10] and soil compaction [11], a disturbance in the balance and availability of nutrients [12], or the species composition of soil microorganisms [13,14].

Currently, there is growing awareness of the need to change the current methods of horticultural production by reducing the doses of fertilisers and crop protection products or replacing them with other means of production, which should be safe to the environment and human health. This might be achieved with biostimulants. In scientific publications, a biostimulant is often defined as any substance or microorganism that is applied to increase the productivity of a plant, its nutrition, and its tolerance to abiotic stress and/or improve its qualitative characteristics, regardless of the content of nutrients [15]. Biostimulants may contain humic and fulvic acids, seaweed extracts, beneficial fungi (mycorrhizal fungi and *Trichoderma* spp.), macro- and micronutrients, and amino acids [16,17]. Amino acids in biostimulants may improve the growth of plants [18] and increase their productivity by stimulating protein biosynthesis, activating enzymes, and facilitating the uptake of macro- and micronutrients [19]. Amino acids are also essential for nitrogen metabolism and chlorophyll biosynthesis [20,21]. The easier uptake of nutrients by plants treated with biostimulants may be a consequence of an increased activity of soil enzymes and microorganisms, improved parameters of the plant root system [22], and possible increased solubility of mineral components in the soil [23]. Biostimulants not only stimulate the uptake of nutrients by plants but also improve the yield quality [24], activate natural immune mechanisms in plants, and increase their resistance to biotic and abiotic stress factors [25,26]. Biostimulants can also be used as growth regulators, being able to accelerate ion absorption and increase the intensity of photosynthesis [27].

The aim of this study was to assess the effect of the foliar application of biostimulants containing organic matter, selected macronutrients, and amino acids on the yield and quality of strawberries grown in a field.

2. Materials and Methods

2.1. Experiment Design

The experiment was conducted in 2021 on a horticultural farm located in the north of the Wielkopolska region (52°52′48.222″ N 16°52′57.814″ E). The material used in the experiment consisted of two-year-old strawberry bushes of the 'Rumba' cultivar, growing in a field. The plants were spaced at 90 × 60 × 25 cm. They grew on luvisol, classified as IVa, with a neutral pH (pH (H_2O) = 7.1). The soil salinity was 0.24 g NaCl dm^{-3}, the humus content was 0.98%, and the volumetric density was 1730 g dm dm^{-3}. The content of macronutrients in the soil was as follows: N-NO_3—20 mg dm^{-3}; P—56 mg dm^{-3}; K—90 mg dm^{-3}; Ca—1085 mg dm^{-3}; Mg—127 mg dm^{-3}.

There were five treatments of the experiment: variant 1—a standard soil fertilisation programme (control); variant 2—as in variant 1, with clean water sprayed on the leaves at a quantity equivalent to variants 3–5; variant 3—foliar spraying with the Calgreen biostimulant; variant 4—foliar spraying with the Eranthis biostimulant; variant 5—foliar spraying with the Greit VG biostimulant. Each variant occupied an area of 240 m^2. Four plots of 20 m^2 each were selected for detailed observation within each variant.

Calgreen is a preparation containing easily assimilable calcium in the form of calcium formate (64% *w*/*w*). It supplements plants with this element and prevents physiological diseases. Eranthis is a preparation stimulating the growth and resistance of plants to stress conditions. It contains organic nitrogen—2.5% *w*/*w* (3.0% *w*/*v*), organic carbon—14% *w*/*w* (16.8% *w*/*v*), and organic matter with a nominal molecular mass < 50 kDa—80%. Greit VG is an organic preparation with a high content of plant-derived free amino acids. The product contains total nitrogen (N)—5% *w*/*w* (6.25% *w*/*v*), organic nitrogen (N)—5% *w*/*w*

(6.25% *w*/*v*), organic carbon (C)—16% *w*/*w* (20% *w*/*v*). The total content of amino acids is 20% *w*/*w* (25% *w*/*v*), and the content of free amino acids is 12% *w*/*w* (15% *w*/*v*). The manufacturer of the preparations is Greenhas Group, Canale, Italy. Each preparation was applied six times to the leaves. When the plants began to flower, their leaves were sprayed every 7 days at a dose of 2.5 L ha in 400 L of water. The plants were sprayed at an air temperature of 14.9–18.6 °C, air humidity of 65.7–74.3%, and wind speed not exceeding 1.4 m/s.

In variants 1 and 2, the Saletrzak Snadard and Polifoska 6 fertilisers (Grupa Azoty S.A., Tarnów, Poland) were applied once at a dose of 100 kg ha^{-1} before the growing season. During the growing season, the plants were fertigated with the Kristalon fertiliser (Grupa Azoty S.A., Poland) twice at a dose of 25 kg. The soil was not fertilised in variants 3, 4, and 5. Weeds in all plots were controlled mechanically. The plants were protected against fungal diseases in accordance with the recommendations for commercial plantations [28]. The assessment of climatic conditions was based on the results of measurements from the nearest weather station.

2.2. Measurements and Observations

2.2.1. Soil Analyses

The soil was analysed twice—in spring 2021 at the beginning of the growing season (baseline analysis) and after the harvest. The analysis included measurements of the volumetric weight of the soil, as well as its acidity; salinity; and the content of macronutrients: N-NO_3, P, K, Mg, and Ca. After the harvest, the content of micronutrients (Zn, Cu, Mn, and Fe) in the soil was also analysed. On both dates, soil samples for analysis were collected from the rhizosphere. Next, the samples were mixed into one collective sample weighing at least 0.5 kg, which was representative for each treatment of the experiment. The content of soil minerals was analysed with the universal method. The following methods were used to measure the content of macronutrients: N-NO_3—microdistillation, P—colorimetric analysis, K and Ca—photometric analysis, Mg—atomic absorption spectrometry (AAS). For extraction of micronutrients from the soil, Lindsay's method was used, and next, the AAS method was used to measure their content. Soil acidity was measured with the potentiometric method. For bulk density, the weight method was used, and the conductivity method was used for the determination of salinity [29].

2.2.2. Leaf and Flowering Intensity Analyses

After harvesting the fruit, leaves for analyses of the content of macro- and micronutrients were collected. Two hundred leaves were collected from the plants in each variant of the experiment. They were dried in a laboratory dryer at an airflow temperature of 65 °C. The content of macronutrients (organic N, P_2O_5, K_2O, CaO, MgO) (in mg dm^{-3}) and micronutrients (Zn, Cu, Mn, Fe) (in % DM) in the leaves was measured. The following methods were used to measure the content of macro- and micronutrients in the leaves: the Kjeldahl distillation method (N), the molybdovanadate method (P), and the atomic absorption spectrometry (AAS) with a Zeiss-Jena AAS-5 apparatus (Oberkochen, Germany) [30].

The flowering intensity was assessed by counting the number of inflorescences and flowers on 50 randomly selected strawberry plants in each variant of the experiment. Then, the number of set fruits on one plant was counted.

2.2.3. Yield and Quality of Strawberries

The yield of strawberry plants was determined by weighing the number of fruits harvested from the entire experimental plot (kg). This number was further converted into tonnes per ha. The fruits were harvested three times: in early, mid-, and late June. After each harvest, the quality of the fruits was assessed according to the following parameters: weight (g), firmness (g mm^{-2}), total soluble solids content (TSS) (°Brix), and colour. Additionally, the percentage of fruit infected with grey mould (*Botrytis cinerea*) was calculated.

In order to assess the average weight, 50 fruits were taken from each variant of the experiment and weighed to the nearest 0.01 g. A Fruit Pressure Tester mod. 302 (FT 02, Facchini Srl, Alfonsine, Italy) for firmness measuring was used. The height and width (mm) of the fruits were measured with a calliper. The total soluble solids (TSS) content was measured with a PR-101a digital refractrometer (ATAGO Co. Ltd., Fukaya-shi, Japan). A sample of 50 fruits was collected from each variant of the experiment to measure both the fruit firmness and the total soluble solids content. The colour of the fruits was assessed with a Minolta colorimeter (Takamatsu, Japan) in the L, a, b colour space (L—lightness from black (0) to white (100), a—colour from green (−60) to red (60), b—colour from blue (−60) to yellow (60)). The resulting values were used to calculate the chromaticity of the colour (Chroma = [(a *)2 + (b *)2]1/2.

To assess the degree of fruit infection with grey mould, the fruits with infection symptoms were counted in each variant, and then the percentage of damaged fruit was calculated. The assessment was carried out after the fruit was harvested and after the sixth days of refrigerated fruit storage at 6 °C. Additionally, after the storage, the fruit firmness and extract content were analysed.

2.2.4. Analysis of Health-Beneficial Substances

The content of sugars (fructose, glucose, sucrose), organic acids (ascorbic, citric, malic), phenolic compounds, and anthocyanins was measured in one collective sample of 50 randomly collected fruits (on three harvest dates) from one variant of the experiment (250 fruits—the total amount in the experiment). The fruits were frozen and stored in polyethylene bags until the analyses. Before the analyses, they were dried at 60 °C and then ground. Analyses for each treatment were performed in 4 replicates.

The content of organic acids was identified and quantified by the HPLC method according to Bozan et al. [31]. Organic acids extraction was performed using 0.25 g of sample mixed with 4 mL of 3% metaphosphoric acid solution. The mixture was ultrasonicated and centrifuged at 5500 rpm for 15 min and was then filtered. The extract of organic acids was analysed using a high-performance liquid chromatographic apparatus HPLC (Shimadzu LC 20A VP, Kyoto, Japan) equipped with a UV detector (Shimadzu SPD 20A VP), and separation was performed using an 87 H LC column (5 µm, 300 × 7.8 mm).

The HPLC technique according to the method developed by Crisosto [32] was used for determination of changes in glucose, fructose, sucrose, and total sugar. A total of 0.5 g of strawberry fruit powder was added to 4 mL of ultrapure water (Millipore Corp., Bedford, MA, USA). The reaction mixture was placed in an ultrasonic bath and ultrasonicated at 80 °C for 15 min, then centrifuged at 5500 rpm for 15 min and filtered before HPLC analysis. Sugar content was determined using an HPLC (Shımadzu, Prominence LC-20A, Kyoto, Japan) RID detector and Coregel-87C LC column (7.8 × 300 mm). Separations were carried out at 70 °C at a flow rate of 0.6 mL min^{-1}. Elution was carried out in isocratic ultrapure water. The contents of sugars were determined according to the external standard calibration curves of the standards used.

The total phenolic content was determined using the Folin–Ciocalteu reagent according to the method of Spanos and Wrolstad [33]. Methanol extract was added to 1 g of samples. Water, Folin–Ciocalteu, and 20% sodium carbonate were added to samples taken from the supernatant of this extract, and then they were stored in the dark for 2 h. The absorbance of all samples was measured at 760 nm using a Thermo Scientific Multiskan GO microplate spectrophotometer (Waltham, MA, USA). Quantities were calculated using a calibration curve prepared daily with known concentrations of gallic acid (GA) standards, and the results were expressed in milligrams of GA equivalents per 100 g of dry weight (DW) of fruit.

The Wrolstad [34] differential pH absorbance method was used for quantification of the monomeric anthocyanin pigment content in a methanolic extract of powdered strawberry fruit in buffers of pH 1.0 (hydrochloric acid–potassium chloride, 0.2 mol) and 4.5 (acetic acid–sodium acetate, 1 M). A UV spectrophotometer and a disposable 1 cm cuvette were

used for spectral measurements at 510 and 700 nm. Anthocyanin content was calculated as mg (cyanidin-3-glucoside).

2.3. Statistical Analysis

The results of the experiment were analysed statistically with the STATISTICA 12.1 software (StatSoft, Inc., Tulsa, OK, USA). The analysis of variance was applied. The differences between the means were assessed with Duncan's test at a significance level of $\alpha = 0.05$.

3. Results and Discussion

3.1. Soil Analyses

We found significant differences in some chemical properties of the soil. The soil pH increased significantly (from 6.4 to 6.8) in the variants where two of the three biostimulants (Calgreen and Eranthis) had been applied to the leaves (Table 1).

Table 1. Some physicochemical properties of the soil.

Treatments	Bulk Density (g dm^{-3})	pH (H_2O)	Salinity (g NaCl dm^{-3})
Soil fertilisation	1670 ± 2.08 a	6.4 ± 0.02 b	0.30 ± 0.025 c
Water spraying	1580 ± 1.71 a	6.7 ± 0.01 c	0.23 ± 0.039 b
Calgreen	1600 ± 3.84 a	6.8 ± 0.12 c	0.19 ± 0.017 a
Eranthis	1540 ± 1.74 a	6.7 ± 0.06 c	0.23 ± 0.049 b
Greit VG	1580 ± 2.50 a	6.2 ± 0.08 a	0.26 ± 0.039 d

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

Soil salinity causes a significant reduction of fresh weight in plants and chlorophyll content [35,36]. The highest soil salinity was observed in the variant with soil fertilisation (0.30 NaCl dm^{-3}). Similarly to soil acidity, a significant decrease in soil salinity was observed in the variants where the biostimulants had been applied. The difference was particularly noticeable in the variant with the Calgreen biostimulant, i.e., a decrease from 0.30 to 0.19 NaCl dm^{-3} (Table 1). An increase in the soil pH and a decrease in soil salinity were reported in an earlier study of Zydlik and Zydlik [37] as effects of biostimulants containing humic acids.

Like most crop plants, strawberry plants require optimal amounts of nutrients for proper growth and yield of fruit. The experiment showed significant differences between the variants in the content of soil macronutrients. In the variant with the Eranthis biostimulant, the content of five of the six macronutrients under analysis was significantly lower than in the control variant. The greatest differences (about 30%) were found in the content of N-NO_3, K, and Cl (Table 2).

Table 2. The content of macronutrients in the soil (mg dm^{-3}).

Treatments	N-NO_3	P	K	Ca	Mg
Soil fertilisation	40.00 ± 4.08 b	72.00 ± 1.63 b	222.75 ± 4.11 d	545.25 ± 4.13 a	119.25 ± 3.30 b
Water spraying	38.25 ± 1.71 b	89.75 ± 2.06 d	161.00 ± 3.79 b	567.25 ± ab 5.75	154.05 ± 4.54 d
Calgreen	31.25 ± 1.26 a	80.25 ± 2.50 c	178.25 ± 1.71 c	708.50 ± 4.51 c	144.25 ± 1.73 c
Eranthis	28.01 ± 0.82 a	67.25 ± 1.26 a	152.50 ± 6.14 a	652.50 ± 8.02 bc	94.00 ± 5.89 a
Greit VG	91.00 ± 1.69 c	100.25 ± 4.11 e	321.25 ± 1.74 e	466.51 ± 2.89 a	157.35 ± 5.74 d

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

In the variant with the Greit VG biostimulant, the content of five of the six macronutrients (except Ca) was significantly higher than in the control variant. The analysis of the content of soil micronutrients revealed a similar trend. In the variant with the Greit VG biostimulant, the content of three of the four micronutrients under analysis (Zn, Cu, Mn) was significantly higher than in the control variant (Table 3). In the other variants, the content of iron and manganese in the soil decreased.

Table 3. The content of micronutrients in the soil (mg dm^{-3}).

Treatments	Zn	Cu	Mn	Fe
Soil fertilisation	3.81 ± 0.01 a	1.55 ± 0.04 a	10.62 ± 0.03 c	179.35 ± 1.26 d
Water spraying	4.74 ± 0.05 b	1.72 ± 0.04 b	11.69 ± 0.08 d	150.83 ± 1.82 c
Calgreen	4.81 ± 0.04 c	1.59 ± 0.06 a	8.81 ± 0.04 b	141.78 ± 4.91 b
Eranthis	5.19 ± 0.05 d	1.56 ± 0.04 a	7.08 ± 0.05 a	129.32 ± 2.51 a
Greit VG	5.82 ± 0.03 e	1.81 ± 0.05 c	14.26 ± 0.06 e	147.38 ± 2.93 c

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

3.2. Content of Minerals in Leaves

The content of macro- and micronutrients in the leaves indicates the nutritional status of plants. In our experiment, the following content of macronutrients was found in the strawberry leaves (in mg dm^{-3}): organic N—2.06–2.26; P—0.58–0.60; K—1.78–2.14; Ca—2.44–2.76; Mg—0.52–0.58 (Table 4).

Table 4. The content of macronutrients in the strawberry leaves (mg dm^{-3}).

Treatments	$N_{org.}$	P	K	Ca	Mg
Soil fertilisation	2.12 ± 0.01 a	0.60 ± 0.03 a	2.03 ± 0.04 a	2.76 ± 0.02 a	0.54 ± 0.01 a
Water spraying	2.11 ± 0.03 a	0.58 ± 0.03 a	1.99 ± 0.03 a	2.17 ± 0.02 b	0.54 ± 0.01 a
Calgreen	2.26 ± 0.03 a	0.60 ± 0.02 a	2.14 ± 0.03 a	2.44 ± 0.01 a	0.52 ± 0.01 a
Eranthis	2.06 ± 0.02 a	0.60 ± 0.02 a	1.97 ± 0.03 a	2.75 ± 0.02 a	0.55 ± 0.01 a
Greit VG	2.13 ± 0.03 a	0.56 ± 0.03 a	1.78 ± 0.02 a	2.85 ± 0.02 a	0.58 ± 0.02 a

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

According to the limits of the content of nutrients in strawberry leaves [38], the content of P, K, Ca, and Mg was high, whereas the N content was optimal. These values indicate a good nutritional status of the plants. It is necessary to stress the fact that both the deficiency and excess of nutrients may be unfavourable for plants. In our experiment, the nitrogen content ranged from 2.06 to 2.13 mg dm^{-3} (Table 4). According to Mereike [39], when the content of this element in strawberry leaves is below 1.9 mg dm^{-3}, leaf necrosis occurs and the leaf surface area decreases. On the other hand, an excessive content of nitrogen (above 4 mg dm^{-3}) delays fruit ripening and causes a loss of fruit firmness [40].

As shown in Table 5, the content of all macronutrients in the leaves of the plants treated with the biostimulants did not differ significantly from the content of macronutrients in the leaves of the plants treated with the soil fertiliser. There was a similar result of the experiment conducted by Soppelsa et al. [26], in which the content of minerals in strawberry leaves and fruits was not significantly affected by the biostimulants applied foliarly or into the soil.

Table 5. The content of micronutrients in the strawberry leaves (in % DM).

Treatments	Zn	Cu	Mn	Fe	B
Soil fertilisation	11.7± 1.24 ab	3.36 ± 0.56 a	80.3 ± 3.34 c	162.4 ± 5.96 ab	36.57 ± 2.93 ab
Water spraying	9.77 ± 0.98 a	3.24 ± 0.38 a	37.2 ± 2.85 a	137.0 ± 4.27 a	35.74 ± 3.64 ab
Calgreen	10.7 ± 0.87 a	3.51 ± 0.41 a	42.0 ± 3.16 a	179.6 ± 3.84 b	32.09 ± 2.17 a
Eranthis	10.4 ± 1.16 a	3.48 ± 0.31 a	54.4 ± 2.48 b	148.9 ± 2.66 a	29.72 ± 2.23 a
Greit VG	17.1 ± 1.24 b	3.59 ± 0.29 a	94.6 ± 4.16 c	175.1 ± 4.12 b	44.25 ± 3.21 b

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

Micronutrients, which are part of most enzymes, regulate biochemical processes in plants. The following content of micronutrients was found in the strawberry leaves: Zn—10.4–17.1% DM; Cu—3.24–3.59% DM; Mg—42.0–94.6% DM; Fe—137–175% DM; B—29.7–44.25% DM (Table 5).

According to the limits of the content of nutrients in strawberry leaves [38], the content of Mn, Fe, and B was optimal, whereas the content of Zn and Cu was low. In our experiment, no significant effect of the biostimulants on the number of micronutrients was observed. The content of Zn, Cu, Fe, and B in the leaves of the plants treated with the biostimulants did not differ significantly from the values in the control variant (Table 5). The only exception was Mn. The content of this element in the leaves of the plants treated with the Calgreen and Eranthis biostimulants was significantly lower than in the control variant.

3.3. Flowering and Fruiting Intensity

The biostimulants used in our experiment had a relatively small influence on the flowering intensity of strawberries. Only in the variant with the Calgreen biostimulant was the number of flowers about 50% greater than in the soil fertilisation variant (Table 6).

Table 6. Flowering and fruiting intensity of strawberries.

Treatments	Number of Flowers per Plant	Number of Fruits per Plant
Soil fertilisation	20.2 ± 0.24 ab	10.5 ± 0.05 a
Water spraying	16.7 ± 0.19 a	9.3 ± 0.03 a
Calgreen	30.1 ± 0.18 c	25.2 ± 0.12 c
Eranthis	20.0 ± 0.18 ab	15.1 ± 0.09 ab
Greit VG	24.6 ± 0.17 b	19.4 ± 0.07 b

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

The number of fruits per plant in this variant was also significantly greater than in the control variant (25 and 10 pcs, respectively). Also, after the application of the Greit VG biostimulant, the number of fruits per plant almost doubled—an increase from 10 to 19 pcs (Table 6).

The yield volume is one of the most important criteria of the profitability of production. In our experiment, the strawberry yield ranged from about 10 to 16 tonnes per ha.

The control plants fertilised in the soil gave the lowest yields at 10.08 t. The plants treated with the biostimulants had significantly higher yields than those fertilised in the soil. In comparison with the control variant, the differences ranged from about 40% (Eranthis—14.15 t) to over 60% (Calgreen—16.32 t). Such a high yield in the variant with the Calgreen biostimulant was the consequence of intensive flowering of the plants, on which a large number of fruits had set (Table 6). Soppelsa et al. [26] also observed a significant increase in yield of strawberries after treating plants with biostimulants.

3.4. Fruit Quality Assessment

The quality of fruits depends on their weight, shape, colour, texture, firmness, and content of acids and sugars. In our experiment, there were considerable differences in the weight of strawberries, which ranged from 16.79 to 21.74 g (Figure 1).

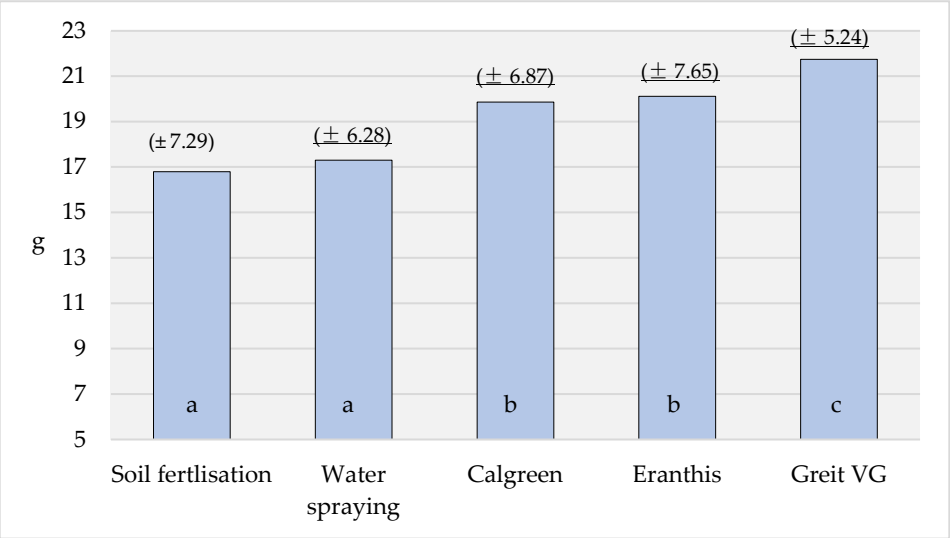


Figure 1. Average weight (g) of strawberry fruit. Values in parentheses present the standard deviation. Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

Geçer et al. [41] observed smaller differences in this parameter in their experiment—from 11.7 g. The fruits with the lowest weight (16.79 g) were harvested from the plants in the control variant. Sayği et al. [42] also harvested strawberries with the lowest weight from plants treated with a mineral fertiliser. In our experiment, a significant increase in the average fruit weight was observed in all three variants with the biostimulants. Depending on the biostimulant, the increase ranged from about 18% (Calgreen) to 30% (Vitorg VG), as compared with the control variant. Bogunovic et al. [43] and Marfa et al. [44] also observed an increase in the average fruit weight after treating plants with biostimulants.

The differences observed in the biometric parameters of strawberries were smaller than those in the fruit weight. The height and width of the fruit in the variants with the Eranthis and Calgreen biostimulants did not differ significantly from the fruit in the soil fertilisation variant (Figure 2).

Only the Greit VG biostimulant caused a significant increase in the biometric parameters of strawberries, whose height and width were a few per cent greater than in the control variant (Figure 2). The positive effect of the Greit VG biostimulant on both the weight of strawberries (Table 6) and their biometric parameters may have been caused by the amino acids contained in it.

Strawberries can be made more attractive to consumers by modifying some of their quality parameters, e.g., firmness, colour, or aroma. Firmness is particularly important, especially for soft fruits, as they can be delivered even to distant markets while maintaining appropriate quality. In our experiment, the firmness of the fruit after harvesting ranged from 158.8 (soil fertilisation) to 215.1 (Eranthis) g mm^{-2} (Table 7).

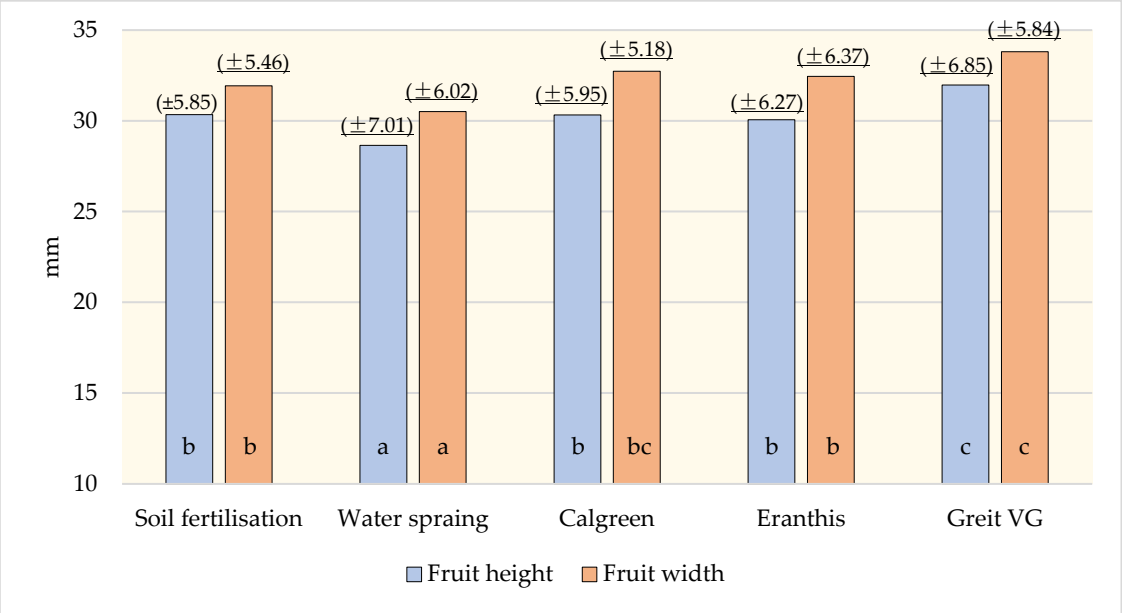


Figure 2. Biometric characteristics (mm) of strawberry fruit. Values in parentheses present the standard deviation. Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

Table 7. Strawberry fruit quality.

Treatments	Firmness (g mm^{-2})		Total Soluble Solids (°Brix)	
	After Harvest	After Storage	After Harvest	After Storage
Soil fertilisation	158.8 ± 24.86 a	132.1 ± 16.52 a	8.54 ± 1.81 a	8.39 ± 0.96 a
Water spraying	164.1 ± 21.25 a	151.8 ± 19.79 b	9.14 ± 1.60 b	8.93 ± 1.13 b
Calgreen	213.1 ± 24.65 b	194.5 ± 23.02 c	9.85 ± 1.63 c	10.39 ± 1.19 d
Eranthis	215.8 ± 28.12 b	195.8 ± 22.88 c	9.88 ± 1.79 c	9.42 ± 1.16 c
Greit VG	215.1 ± 24.04 b	194.6 ± 19.96 c	10.16 ± 1.62 c	9.71 ± 0.98 c

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

These values were similar to the results of the experiments conducted by Kilic et al. [45] and Sayği et al. [42]. In the variants with the foliar application of biostimulants, the firmness of the fruit after harvesting was several dozen percent greater than in the soil fertilisation variant. The Eranthis and Greit VG biostimulants increased the fruit firmness by about 36%, whereas Calgreen increased it by about 34%. The Calgreen biostimulant contains calcium, an element that determines the stiffness of cell walls, one that is particularly important for the transport and storage of soft fruits. The use of calcium, especially before harvesting strawberries, improves their firmness and increases their marketable yield [46,47]. The significant increase in strawberry fruit firmness under the influence of biostimulants is also reported by Soppelsa et al. [26].

The firmness of strawberries stored for several days decreased significantly. Again, the fruit harvested from the plants fertilised in the soil were characterised by the lowest firmness (132.1 g mm^{-2}) (Table 7). Drobek et al. [48] observed a significant decrease of about 70% in the firmness of strawberries after their storage for several days. The firmness of stored fruit harvested from the plants which had been treated with the biostimulants several times was significantly higher than the firmness of the fruit in the control variant (Table 7).

The total soluble solids (TSS) content is a determinant of the taste of fruits [49]. In our experiment, the TSS content in the strawberries ranged from 8.54 to 10.16 °Brix. The fruits in the control variant were characterised by the lowest TSS value (8.54 °Brix) (Table 7). In the experiment conducted by Kilic et al. [45], strawberries with the lowest TSS content were also harvested in the mineral fertilisation variant. There were lower TSS values observed in the experiments conducted by Contessa et al. [50] (5.5 °Brix), Cvelbar et al. [47] (8.0 °Brix), and Agehara et al. [51] (6.32 °Brix). In our experiment, each of the three biostimulants increased the TSS content significantly. The Greit VG biostimulant was the most effective as it increased the TSS content by about 19%. The other two biostimulants were only slightly less effective. The values measured in our experiment were different from those recorded in the experiments conducted by Sayği et al. [42], who examined the effect of various forms of soil fertilisation on strawberry plantations. The differences may have been caused by the influence of other factors on the content of extract in the fruit. According to Saridas et al. [52], the quality of berries depends on the cultivation and environmental conditions, cultivar, degree of fruit ripeness, cultivation methods, and storage conditions. Aguero et al. [53] did not observe any influence of air temperature on the TSS content in several cultivars of strawberries. The analysis of the content of extract in strawberries after storage confirmed the positive effect of biostimulants on this parameter, regardless of the type of biostimulant used.

As can be seen in Table 8, the harvest date was the parameter that significantly influenced the quality of strawberries in our experiment. The fruits harvested on the first date, in early June, were the heaviest (25.39 g), but they had the lowest firmness (188.3 g mm^{-2}) and TSS content (8.53 °Brix). The fruits harvested on the subsequent dates had significantly lower weights but significantly greater firmness (the second date) and extract content, which was over 30% higher (on the third date).

Table 8. Effect of the harvest date on quality of strawberries.

Harvest Date	Fruit Weight (g)	Firmness (g mm^{-2})	Total Soluble Solids (°Brix)
Beginning of June	25.39 ± 9.02 b	188.3 ± 29.01 a	8.53 ± 1.00 a
Mid-June	16.80 ± 4.39 a	206.9 ± 24.64 b	8.92 ± 0.80 b
End of June	16.26 ± 6.92 a	194.9 ± 12.47 a	11.06 ± 1.44 c

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

The colour of fruit is an important indicator of the degree of its ripeness [54]. The average consumer pays attention first to the appearance of the fruit, and then to its taste. Our study showed that the intensity of the colour of strawberries differed significantly in a variant-dependent manner. The analysis of the colour intensity (parameter L) showed that the fruits from the soil fertilisation variant were darker than those from the variants treated with the Calgreen biostimulant, and especially with the Greit VG biostimulant (Table 9).

Table 9. Intensity of the colour of strawberries.

Treatments	L	a	b	Chroma
Soil fertilisation	26.46 ± 2.54 c	26.38 ± 4.16 b	19.49 ± 3.86 cd	45.87 ± 7.02 b
Water spraying	26.66 ± 2.62 c	27.89 ± 4.32 c	20.22 ± 5.18 d	48.11 ± 8.44 c
Calgreen	25.63 ± 2.89 b	25.53 ± 4.92 b	17.87 ± 4.09 b	43.40 ± 8.42 b
Eranthis	26.22 ± 2.73 bc	26.41 ± 4.93 b	18.61 ± 4,43 bc	45.02 ± 8.97 b
Greit VG	24.86 ± 2.06 a	24.13 ± 4.85 a	16.43 ± 3.62 a	40.56 ± 5.73 a

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

Measurements of the 'a' coordinate (the colour range from green to red) and the 'b' coordinate (the colour range from blue to yellow) showed that the colour of the fruit harvested from the bushes fertilised in the soil was more intense than that of the fruit harvested from the bushes treated with the biostimulants (Table 9). The higher the value of the 'a' coordinate, the higher the intensity of red. The values of the colour intensity of strawberries measured in our experiment were similar to the results obtained by Gündüz et al. [55] (L = 25.76) and Sayği et al. [42] (L = 27.4), but they were lower than in the experiments conducted by Kilic et al. [45] (L = 33.43) and Agehara et al. [51] (L = 38.9).

Firm fruits, which consumers prefer, are less likely to be damaged by grey mould, caused by the *Botrytis cinerea* fungus. In our experiment, the strawberries were slightly infected with this pathogen after harvest. The share of fruits with grey mould symptoms in the control variant did not exceed 3%. In the variants with the biostimulants, there were no fruits attacked by grey mould (Figure 3). The percentage of infection increased significantly after a week of fruit storage. This was particularly noticeable in the fruit harvested from the plants in the soil fertilisation variant (about 15%). The percentage of fruit infected with grey mould in the variants with the biostimulants was even several times lower—it ranged from 2.5 to 2.8% (Figure 3). The fruit rot may have been reduced by the positive effect of the biostimulants, which thickened the cell walls and thus limited the penetration of fungi into the cells.

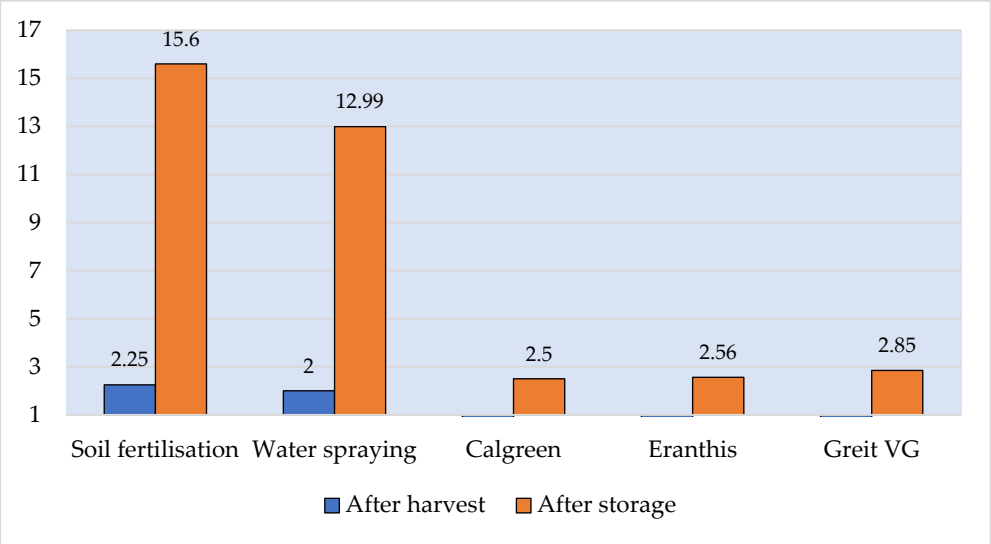


Figure 3. Percentage of strawberry fruit infected by grey mould.

The sugar content determines the taste of fruit [49]. In our experiment, there were relatively small differences in the total sugar content in the strawberries, which ranged from 11.88 (Calgreen) to 12.79 mg 100 g^{-1} (Eranthis) (Table 10).

Table 10. The sugar content in strawberry fruit (in mg 100 g^{-1}).

Treatments	Fructose	Glucose	Sucrose	Total Sugars
Soil fertilisation	5.02 ± 0.15 b	7.09 ± 0.38 b	0.31 ± 0.01 a	12.42 ± 0.23 c
Water spraying	5.06 ± 0.15 a	7.13 ± 0.03 a	0.45 ± 0.04 b	12.64 ± 0.14 b
Calgreen	4.85 ± 0.05 a	6.76 ± 0.21 a	0.33 ± 0.01 a	11.88 ± 0.15 a
Eranthis	5.12 ± 0.25 a	7.19 ± 0.32 a	0.47 ± 0.02 b	12.79 ± 0.61 b
Greit VG	4.95 ± 0.12 a	7.25 ± 0.06 a	0.36 ± 0.02 a	12.56 ± 0.15 ab

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

Such values were lower than those recorded in the experiments conducted by Paparozzi et al. [56] at 4.18–9.98% and Gündüz et al. [55] at 4.48–6.28%. The most common sugars in strawberries are sucrose, glucose, and fructose. In our experiment, the following contents of these sugars were found: fructose—4.85–5.12 mg 100 g^{-1}, glucose—6.76–7.25 mg 100 g^{-1}, and sucrose—0.33–0.47 mg 100 g^{-1} (Table 10). These values were greater than those recorded in the experiments conducted by Mahmood et al. [57] and Kilic et al. [45]. No significant increase in the fruit sugar content was observed in the variants with the biostimulants. Soltaniband et al. [58] also found no effect of biostimulants on the sugar content in strawberries.

In our experiment, the strawberries contained the most glucose and the least sucrose. These results were different from those recorded in the experiment by Urün et al. [1], who found the highest concentration of fructose, especially in ripe fruit. According to Lee [59], sucrose is the main soluble sugar in strawberry cultivars with low sugar content. Differences in the content of soluble sugars in fruits may be influenced by internal factors (genotypic differences) or external factors (environmental conditions, cultivar, cultivation conditions). According to Kafkas et al. [60], the degree of fruit ripeness is the most important factor influencing the content of sugars and organic acids in strawberries.

The taste of strawberries is influenced not only by their content of sugars but also by the amount of organic acids in them [49]. In our experiment, the content of ascorbic acid in the fruit ranged from 94.9 to 139.46 mg 100 g^{-1}, citric acid—from 15.41 to 23.22 mg 100 g^{-1}, and malic acid—from 2.61 to 3.10 mg 100 g^{-1} (Table 11).

Table 11. The content of organic acid in strawberry fruit (in mg 100 g^{-1}).

Treatments	Ascorbic Acid	Citric Acid	Malic Acid
Soil fertilisation	94.94 ± 15.66 a	15.41 ± 1.98 a	2.78 ± 0.25 ab
Water spraying	101.36 ± 26.76 a	16.65 ± 0.33 ab	2.61 ± 0.94 a
Calgreen	139.46 ± 13.94 b	23.22 ± 2.04 c	3.48 ± 0.35 b
Eranthis	87.41 ± 5.56 a	23.14 ± 4.68 c	3.10 ± 0.36 ab
Greit VG	122.13 ± 15.30 ab	19.70 ± 1.95 bc	2.87 ± 0.51 ab

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

These values were noticeably greater than those recorded in the experiments conducted by Kilic et al. [45]. In our experiment, the strawberries had the highest content of ascorbic acid and the lowest content of malic acid (Table 11). Different results from the one obtained in our experiment were presented by Mahmood et al. [57], Gündüz et al. [61], and Urün et al. [1], who found the largest amount of citric acid in strawberries. Similarly to sugars, external factors may significantly influence the content of organic acids in strawberries. In our experiment, there were no significant differences in the content of either ascorbic or malic acid in the strawberries. However, there were such differences in the content of citric acid. The strawberries harvested from the bushes treated with the biostimulants, regardless of the type, had significantly higher content of this acid than the fruit in the control variant. The differences ranged from 17.7 (Greit VG) to 23.22 mg 100 g^{-1} (Calgreen) (Table 11).

Anthocyanins and phenolic compounds, which can be found in the edible organs of various plants, have anti-inflammatory and anticancer properties [62,63], and they prevent DNA damage [3]. In our experiment, there were no significant differences in the content of phenolic compounds in the strawberries. Depending on the variant, their content ranged from 164.45 to 172.1 mg GAE 100 g^{-1} DM (Table 12).

Table 12. The content of health-beneficial substances in the strawberries.

Treatments	Phenolic Compounds (mg GAE 100 g^{-1} DM)	Anthocyanins (mg 100 g^{-1} DM)
Soil fertilisation	1685.38 ± 17.45 b	7.71 ± 0.86 bc
Water spraying	1644.57 ± 32.86 a	4.98 ± 2.24 a
Calgreen	1621.82 ± 3.82 b	8.36 ± 0.87 c
Eranthis	1708.44 ± 12.25 b	8.03 ± 1.12 c
Greit VG	1721.66 ± 18.69 b	6.67 ± 1.17 b

Means marked with the same letters did not differ significantly (according to Duncan's test, significance level $\alpha = 0.05$).

These values were higher than those recorded in the experiment conducted by Urün et al. [1] but lower than those observed by Oz et al. [64] and Agehara et al. [51] in their experiments. The biostimulants used in our experiment did not have a significant effect on the content of polyphenols in the strawberries. Soltaniband et al. [58] arrived at a similar conclusion after their experiment.

As mentioned earlier, anthocyanins have antioxidative properties. This fact was confirmed by Wang et al. [65], who observed a positive correlation between the level of antioxidative activity of strawberries and the content of anthocyanins in these fruits. Their amount depends on the fruit colour intensity. The redder the strawberries are, the more anthocyanins they contain [51]. Our experiment confirmed this conclusion. The highest content of anthocyanins (7.71 mg 100 g^{-1} DM) was found in the strawberries harvested from the bushes fertilised in the soil (Table 12). They also had the highest colour intensity measured with the L value (Table 9).

All three biostimulants used in our experiment did not change the content of anthocyanins in the strawberries. The content of these compounds in the variants with the Eratnthis and Greit VG biostimulants was higher (8.36 and 8.03 mg 100 g^{-1} DM, respectively) than in the control variant (7.71 mg 100 g^{-1} DM). However, the statistical analysis did not confirm the significance of these differences. Cvelbar et al. [47] analysed the effect of mineral fertilisation on the quality of strawberries and found no differences in the content of anthocyanins in the fruits. According to Agüero et al. [53], the qualitative characteristics of strawberries (including firmness, the content of extract and anthocyanins) are more influenced by the air temperature and rainfall than by the supply of nutrients available to plants. According to Michalska et al. [66] and Kruger et al. [67], high temperatures and exposure to light (photoperiod, wavelength) accelerate metabolic processes in plant cells, thus facilitating the synthesis of anthocyanins in fruits. This fact was confirmed by Balasooriya [68] and Cervantes [69], who showed a positive correlation between the content of anthocyanins and air temperature.

4. Conclusions

Our experiment was an attempt to assess the usefulness of three biostimulants for improving the yield and quality of strawberries. It showed that the yield of the plants which had been treated with the biostimulants several times during the growing season increased significantly. The yield was about 40% (Eranthis and Greit VG) or 60% (Calgreen) higher than in the variant where mineral fertilisers had been applied into the soil. The qualitative parameters of the fruit also improved. Each of the biostimulants increased the average weight, firmness (an increase of about 30%), and the total soluble solids (TSS) content in the fruit. This effect was observed by analysing the quality of the fruit both after the harvest and after six days of storage. This result is particularly important for soft berries such as strawberries. Firmer fruits are less susceptible to pathogens. In our experiment, the fruits harvested from the plants treated with the biostimulants were less likely to be infected by grey mould, caused by the *Botrytis cinerea* fungus, both in the post-harvest period and after their storage. There were no significant differences in the content of sugars,

organic acids (except citric acid), phenolic compounds, or anthocyanins in the strawberries. The biostimulants used in our experiment, especially those containing amino acids and calcium, may significantly improve the quality of strawberries and their preservation.

Author Contributions: Conceptualisation, Z.Z. and P.Z.; methodology, Z.Z. and N.E.K.; formal analysis, Z.Z.; investigation, Z.Z. and P.Z.; resources, Z.Z. and N.E.K.; data curation, P.Z. and Z.Z.; writing—original draft preparation, P.Z.; writing—review and editing, Z.Z.; visualisation, P.Z.; project administration, P.Z.; funding acquisition, Z.Z. and N.E.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Urün, I.; Attar, S.H.; Sönmez, D.A.; Gündesli, M.A.; Erci¸sli, S.; Kafkas, N.E.; Bandic, L.M.; Duralija, B. Comparison of polyphenol, sugar, organic acid, volatile compounds, and antioxidant capacity of commercially grown strawberry cultivars in Turkey. *Plants* **2021**, *10*, 1654. [CrossRef] [PubMed]
2. Mazzoni, L.; Perez-Lopez, P.; Giampieri, F.; Alvarez-Suarez, J.M.; Gasparrini, M.; Forbes-Hernandez, T.Y.; Quiles, J.L.; Mezzett, B.; Battino, M. The genetic aspects of berries: From field to health. *J. Sci. Food Agric.* **2015**, *96*, 365–371. [CrossRef] [PubMed]
3. Giampieri, F.; Forbes-Hernandez, T.Y.; Gasparrini, M.; Alvarez-Suarez, J.M.; Afrin, S.; Bompadre, S.; Quiles, J.L.; Mezzetti, B.; Battino, M. Strawberry as a health promoter: An evidence based review. *Food Funct.* **2015**, *6*, 1386–1398. [CrossRef] [PubMed]
4. Muthukumaran, S.; Tranchant, C.; Shi, J.; Ye, X.; Xue, S.J. Ellagic acid in strawberry (*Fragaria* spp.): Biological, technological, stability, and human health aspects. *Food Qual. Saf.* **2017**, *1*, 227–252. [CrossRef]
5. Sapei, L.; Hwa, L. Study on the Kinetics of Vitamin C Degradation in Fresh Strawberry Juices. *Procedia Chem.* **2014**, *9*, 62–68. [CrossRef]
6. Santos, B.M.; Chandler, C.K. Influence of nitrogen fertilization rates on the performance of strawberry cultivars. *Int. J. Fruit Sci.* **2009**, *9*, 126–135. [CrossRef]
7. Hamedi, B.; Pirbalouti, A.G.; Rajabzadeh, F. Manures, vermicompost, and chemical fertilizer impacts on the yield and volatile compounds of the damask rose (*Rosa damascena* Mill.) flower petals. *Ind. Crop Prod.* **2022**, *187*, 115470. [CrossRef]
8. Dutta, D.; Singh, V.K.; Upadhyay, P.K.; Meena, A.L.; Kumar, A.; Mishra, R.P.; Dwivedi, B.S.; Shukla, A.K.; Yadav, G.S.; Tewari, R.B.; et al. Long-term impact of organic and inorganic fertilizers on soil organic carbon dynamics in a rice-wheat system. *Land Degrad. Dev.* **2022**, *33*, 1862–1877. [CrossRef]
9. Zavyalova, N.E.; Vasbieva, M.T.; Yamaltdinova, V.R.; Shlyapina, Y.V. Characteristics of humic acids in sod-podzolic soil under long-term exposure to different fertilization systems. *Dokuchaev Soil Bull.* **2022**, *111*, 97–115. [CrossRef]
10. Song, H.; Che, Z.; Cao, W.C.; Huang, T.; Wang, J.G.; Dong, Z.R. Changing roles of ammonia-oxidizing bacteria and archaea in a continuously acidifying soil caused by over-fertilization with nitrogen. *Environ. Sci. Pollut.* **2016**, *23*, 11964–11974. [CrossRef]
11. Wang, X.B.; Wang, X.L.; Sheng, H.J.; Wang, X.Z.; Zhao, H.T.; Feng, K. Excessive Nitrogen Fertilizer Application Causes Rapid Degradation of Greenhouse Soil in China. *Pol. J. Environ. Stud.* **2022**, *31*, 1527–1534. [CrossRef]
12. Bhatt, M.K.; Raverkar, K.P.; Chandra, R.; Pareek, N.; Labanya, R.; Kumar, V.; Kaushik, S.; Singh, D.K. Effect of long-term balanced and imbalanced inorganic fertilizer and FYM application on chemical fraction of DTPA-extractable micronutrients and yields under rice-wheat cropping system in mollisols. *Soil Use Manag.* **2020**, *36*, 261–273. [CrossRef]
13. Sas-Paszt, L.; Sumorok, B.; Derkowska, E.; Trzciński, P.; Lisek, A.; Grzyb, Z.; Sitarek, M.; Przybył, M.; Frąc, M. Effect of microbiologically enriched fertilizers on the vegetative growth of strawberry plants under field conditions in the first year of plantation. *J. Res. Appl. Agric. Eng.* **2019**, *64*, 29–37.
14. Bebber, D.P.; Richards, V.R. A meta-analysis of the effect of organic and mineral fertilizers on soil microbial diversity. *Appl. Soil Ecol.* **2022**, *175*, 104450. [CrossRef]
15. Du Jardin, P. Plant biostimulants: Definition, concept, main categories and regulation. *Sci. Hortic.* **2015**, *196*, 3–14. [CrossRef]
16. Canellas, L.P.; Olivares, F.L.; Aguiar, N.O.; Jones, D.L.; Nebbioso, A.; Mazzei, P.; Piccolo, A. Humic and fulvic acids as biostimulants in horticulture. *Sci. Hortic.* **2015**, *196*, 15–27. [CrossRef]
17. Rouphael, Y.; Colla, G. Biostimulants in agriculture. *Front. Plant Sci.* **2020**, *11*, 40. [CrossRef] [PubMed]
18. Cerdán, M.; Sánchez-Sánchez, A.; Jordá, J.D.; Juárez, M.; Sánchez-Andreu, J. Effect of commercial amino acids on iron nutrition of tomato plants grown under lime-induced iron deficiency. *J. Plant Nutr. Soil Sci.* **2013**, *176*, 859–866. [CrossRef]
19. De Pascale, S.; Rouphael, Y.; Colla, G. Plant biostimulants: Innovative tool for enhancing plant nutrition in organic farming. *Eur. J. Hortic. Sci.* **2018**, *82*, 277–285. [CrossRef]

20. Kałuzewicz, A.; Krzesiński, W.; Spizewski, T.; Zaworska, A. Effect of biostimulants on several physiological characteristics and chlorophyll content in broccoli under drought stress and re-watering. *Not. Bot. Horti Agrobot. Cluj-Napoca* **2017**, *45*, 197–202. [CrossRef]
21. Bulgari, R.; Franzoni, G.; Ferrante, A. Biostimulants application in horticultural crops under abiotic stress conditions. *Agronomy* **2019**, *9*, 306. [CrossRef]
22. Mattner, S.W.; Milinkovic, M.; Arioli, T. Increased growth response of strawberry roots to a commercial extract from *Durvillaea potatorum* and *Ascophyllum nodosum*. *J. Appl. Phycol.* **2018**, *30*, 2943–2951. [CrossRef]
23. Halpern, M.; Bar-Tal, A.; Ofek, M.; Minz, D.; Muller, T.; Yermiyahu, U. The use of biostimulants for enhancing nutrient uptake. In *Advances in Agronomy*; Sparks, D.L., Ed.; Elsevier Science Publishing Co., Inc.: San Diego, CA, USA, 2015; Volume 130, pp. 141–174, ISBN 978-0-12-802137-8.
24. Calvo, P.; Nelson, L.; Kloepper, J.W. Agricultural uses of plant biostimulants. *Plant Soil* **2014**, *383*, 3–41. [CrossRef]
25. Di Stasio, E.; Van Oosten, M.J.; Silletti, S.; Raimondi, G.; dell'Aversana, E.; Carillo, P.; Maggio, A. Ascophyllum nodosum-based algal extracts act as enhancers of growth, fruit quality, and adaptation to stress in salinized tomato plants. *J. Appl. Phycol.* **2018**, *30*, 2675–2686. [CrossRef]
26. Soppelsa, S.; Kelderer, M.; Casera, C.; Bassi, M.; Robatscher, P.; Matteazzi, A.; Andreotti, C. Foliar Applications of Biostimulants Promote Growth, Yield and Fruit Quality of Strawberry Plants Grown under Nutrient Limitation. *Agronomy* **2019**, *9*, 483. [CrossRef]
27. Teklić, T.; Paradiković, N.; Špoljarević, M.; Zeljković, S.; Lončarić, Z.; Lisjak, M. Linking abiotic stress, plant metabolites, biostimulants and functional food. *Ann. Appl. Biol.* **2021**, *178*, 169–191. [CrossRef]
28. Tartanus, M.; Masny, S. (Eds.) *Metodyka Integrowanej Ochrony Truskawki*; Pub. Instytut Ogrodnictwa: Skierniewice, Poland, 2013; pp. 1–80. (In Polish)
29. Ostrowska, A.; Gawliński, S.; Szczubiałka, Z. *Metody Analizy i Oceny Właściwości Gleb i Roslin. Katalog*; Pub. Instytut Ochrony Roślin: Warszawa, Poland, 1991; pp. 245–279. (In Polish)
30. IUNG. *Analytical Methods in Agricultural Chemistry Stations Part II. Plant Analyses*; Institute of Soil Science and Plant Cultivation: Puławy, Poland, 1972; pp. 25–83.
31. Bozan, B.; Baser, K.H.C.; Kara, S. Quantitative determination of naphthaquinones of *Arnebia densiflora* (Nordm.) Ledeb. by an improved high-performance liquid chromatographic method. *J. Chromatogr. A* **1997**, *782*, 133–136. [CrossRef]
32. Crisisto, C.H.; Slaughter, D.; Garner, D. Developing maximum maturity indices for "Tree ripe" fruit. *Adv. Hortic. Sci.* **2004**, *18*, 29–32.
33. Spanos, G.A.; Wrolstad, R.E.; Heatherbell, D.A. Influence of processing and storage on the phenolic composition of apple juice. *J. Agric. Food Chem.* **1990**, *8*, 1572–1579. [CrossRef]
34. Wrolstad, R.E. Color and pigment analysis in fruit products. In *Station Bulletin*; University of Agricultural Experimental Station Oregon State: Corvallis, OR, USA, 1976; Volume 624, p. 16.
35. Taïbi, K.; Taïbi, F.; Ait Abderrahim, L.; Ennajah, A.; Belkhodja, M.; Mulet, J.M. Effect of salt stress on growth, chlorophyll content, lipid peroxidation and antioxidant defence systems in *Phaseolus vulgaris* L. *S. Afr. J. Bot.* **2016**, *105*, 306–312. [CrossRef]
36. Yarsi, G.; Sivaci, A.; Dasgan, H.Y.; Altuntas, O.; Binzet, R.; Akhoundnejad, Y. Effects of salinity stress on chlorophyll and carotenoid contents and stomata size of grafted and ungrafted galia C8 melon cultivar. *Pak. J. Bot.* **2017**, *49*, 421–426.
37. Zydlik, Z.; Zydlik, P. The Effect of a Preparation Containing Humic Acids on the Growth, Yield, and Quality of Strawberry Fruits (*Fragaria* x *ananassa* (Duchesne ex Weston) Duchesne ex Rozier). *Agronomy* **2023**, *13*, 1872. [CrossRef]
38. Wójcik, P. *Analiza Mineralna Liści—Uaktualnione Kryterium Diagnostyczne w Nawożeniu Roślin Sadowniczych*; Instytut Ogrodnictwa: Skierniewice, Poland, 2021; p. 20. (In Polish)
39. Mareike Jezek, M.; Zörb, O.C.; Merkt, N.; Geilfus, C.M. Anthocyanin Management in Fruits by fertilization. *J. Agric. Food Chem.* **2018**, *66*, 753–764. [CrossRef]
40. Guinto, D.F. Nitrogen fertilisation effects on the quality of selected crops: A review. *Agron. N. Z.* **2016**, *46*, 121–132.
41. Geçer, M.K.; Gündoğdu, M.; Başar, G. Bazi Çilek Çeşitlerinin Merzifon (Amasya) Ekolojisindeki Verim Durumlarinin Tespiti. Iğdir Univ. *J. Inst. Sci. Technol.* **2018**, *8*, 11–15. [CrossRef]
42. Sayği, H. Effects of Organic Fertilizer Application on Strawberry (*Fragaria vesca* L.) Cultivation. *Agronomy* **2022**, *12*, 1233. [CrossRef]
43. Marfà, O.; Cáceres, R.; Polo, J.; Ródenas, J. Animal protein hydrolysate as a biostimulant for transplanted strawberry plants subjected to cold stress. *Acta Hortic.* **2009**, *842*, 315–318. [CrossRef]
44. Bogunovic, I.; Duralija, B.; Gadze, J.; Kisic, I. Biostimulant usage for preserving strawberries to climate damages. *Hortic. Sci.* **2015**, *42*, 132–140. [CrossRef]
45. Kilic, N.; Burgut, A.; Gündesli, M.A.; Nogay, G.; Ercisli, S.; Kafkas, N.E.; Ekiert, H.; Elansary, H.O.; Szopa, A. The Effect of Organic, Inorganic Fertilizers and Their Combinations on Fruit Quality Parameters in Strawberry. *Horticulturae* **2021**, *7*, 354. [CrossRef]
46. Singh, S.; Singh, N.P.; Sharda, R.; Sangwan, A.K. Response of irrigation, fertigation and mulching on plant growth and fruit yield of strawberry. *Indian J. Hortic.* **2019**, *76*, 233–240. [CrossRef]
47. Cvelbar Weber, N.; Koron, D.; Jakopic, J.; Veberic, R.; Hudina, M.; Baša Cesnik, H. Influence of Nitrogen, Calcium and Nano-Fertilizer on Strawberry (*Fragaria ananasa* Duch.) Fruit Inner and Outer Quality. *Agronomy* **2021**, *11*, 997. [CrossRef]

48. Drobek, M.; Frąc, M.; Zdunek, A.; Cybulska, J. The effect of cultivation method of strawberry (*Fragaria* x *ananassa* Duch.) cv. Honeoye on structure and degradation dynamics of pectin during cold storage. *Molecules* **2020**, *25*, 4325. [CrossRef] [PubMed]
49. Milukic-Petkovsek, M.; Ivancic, A.; Schimitzer, V.; Veberic, R.; Stampar, F. Comparison of major taste compounds and antioxidative properties of fruits and flowers of different Sambucus species and interspecific hybrids. *Food Chem.* **2016**, *200*, 134–140. [CrossRef]
50. Contessa, C.; Mellano, M.G.; Beccaro, G.L.; Giusiano, A.; Botta, R. Total antioxidant capacity and total phenolic and anthocyanin contents in fruit species grown in Northwest Italy. *Sci. Hortic.* **2013**, *160*, 351–357. [CrossRef]
51. Agehara, S.; Nunes, M.C.d.N. Season and nitrogen fertilization effects on yield and physicochemical attributes of strawberry under subtropical climate conditions. *Agronomy* **2021**, *11*, 1391. [CrossRef]
52. Saridas, M. Seasonal variation of strawberry fruit quality in widely grown cultivars under Mediterranean climate condition. *J. Food Compos. Anal.* **2021**, *97*, 1033733. [CrossRef]
53. Agüero, J.J.; Salazar, S.M.; Kirschbaum, D.S.; Jerez, E.F. Factors affecting fruit quality in strawberries grown in a subtropical environment. *Int. J. Fruit Sci.* **2015**, *15*, 223–234. [CrossRef]
54. Ayour, J.; Sagar, M.N.; Alfeddy, M.; Taourirte, M.; Benichou, M. Evolution of pigments and their relationship with skin color based on ripening in fruits of different Moroccan genotypes of apricots (*Prunus armeniaca* L.). *Sci. Hortic.* **2016**, *207*, 168–175. [CrossRef]
55. Gündüz, K.; Özbay, H. The effects of genotype and altitude of the growing location on physical, chemical, and phytochemical properties of strawberry. *Turk. J. Agric. For.* **2018**, *42*, 145–153. [CrossRef]
56. Paparozzi, E.T.; Meyer, G.E.; Schlegel, V.; Blankenship, E.E.; Stacy, A.; Adams, S.A.; Conley, M.E.; Loseke, B.; Read, P.E. Strawberry cultivars vary in productivity, sugars and phytonutrient content when grown in a greenhouse during the winter. *Sci. Hortic.* **2018**, *227*, 1–9. [CrossRef]
57. Mahmood, T.; Anwar, F.; Abbas, M.; Saari, N. Effect of maturity on phenolics (phenolic acids and flavonoids) profile of strawberry cultivars and mulberry species from Pakistan. *Int. J. Mol. Sci.* **2012**, *13*, 4591–4607. [CrossRef] [PubMed]
58. Soltaniband, V.; Brégard, A.; Gaudreau, L.; Dorais, M. Biostimulants Promote Plant Development, Crop Productivity, and Fruit Quality of Protected Strawberries. *Agronomy* **2022**, *12*, 1684. [CrossRef]
59. Lee, J.; Kim, H.B.; Noh, Y.H.; Min, S.R.; Lee, H.S.; Jung, J.; Park, K.H.; Kim, D.S.; Nam, M.H.; Kim, T.I. Sugar content and expression of sugar metabolism-related gene in strawberry fruits from various cultivars. *J. Plant Biotechnol.* **2018**, *45*, 90–101. [CrossRef]
60. Kafkas, N.E.; Koşar, M.; Paydaş, S.; Kafkas, S.; Başer, K.H.C. Quality characteristics of strawberry genotypes at different maturation stages. *Food Chem.* **2007**, *100*, 1229–1236. [CrossRef]
61. Gündüz, K.; Ozdemir, E. The effects of genotype and growing conditions on antioxidant capacity, phenolic compounds, organic acid and individual sugars of strawberry. *Food Chem.* **2014**, *155*, 298–303. [CrossRef] [PubMed]
62. Kim, I.; Lee, J. Variations in anthocyanin profiles and antioxidant activity of 12 genotypes of mulberry (*Morus* spp.) fruits and their changes during processing. *Antioxidants* **2020**, *9*, 242. [CrossRef]
63. Speer, H.; D'Cunha, N.M.; Alexopoulos, N.I.; McKune, A.J.; Naumovski, N. Anthocyanins and human health—A focus on oxidative stress, inflammation and disease. *Antioxidants* **2020**, *9*, 366. [CrossRef]
64. Oz, A.T.; Baktemur, G.; Kargi, S.P.; Kafkas, E. Volatile compounds of strawberry varieties. *Chem. Nat. Compd.* **2016**, *52*, 507–509. [CrossRef]
65. Wang, S.Y.; Lin, H.S. Antioxidant activity in fruits and leaves of blackberry, raspberry, and strawberry varies with cultivar and developmental stage. *J. Agric. Food Chem.* **2000**, *48*, 140–146. [CrossRef]
66. Michalska, A.; Carlen, C.; Heritier, J.; Andlauer, W. Profiles of bioactive compounds in fruits and leaves of strawberry cultivars. *J. Berry Res.* **2017**, *7*, 71–84. [CrossRef]
67. Krüger, E.; Will, F.; Kumar, K.; Celejewska, K.; Chartier, P.; Masny, A.; Mott, D.; Petit, A.; Savini, G.; Sønsteby, A. Influence of Post-Flowering Climate Conditions on Anthocyanin Profile of Strawberry Cultivars Grown from North to South Europe. *Appl. Sci.* **2021**, *11*, 1326. [CrossRef]
68. Balasooriya, B.L.H.N.; Dassanayake, K.; Ajlouni, S. High temperature effects on strawberry fruit quality and antioxidant contents. *Acta Hortic.* **2020**, *1278*, 225–234. [CrossRef]
69. Cervantes, L.; Ariza, M.T.; Gómez-Mora, J.A.; Miranda, L.; Medina, J.J.; Soria, C.; Martínez-Ferri, E. Light exposure affects fruit quality in different strawberry cultivars under field conditions. *Sci. Hortic.* **2019**, *252*, 291–297. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.