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The Effect of Mycorrhiza Fungi and Various Mineral Fertilizer Levels on the Growth, Yield, and Nutritional Value of Sweet Pepper (*Capsicum annuum* L.)

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Abstract: Mycorrhizal fungi can increase the effectiveness of a mineral fertilizer top dressing, positively affecting sweet pepper yield and quality. For this reason, an experiment was carried out between 2014 and 2016 to study the effect of top dressing doses and the inoculation of the root system with mycorrhizal fungi on the growth and yield of sweet pepper and the content of nutrients and macro- and microelements in the fruits. Root inoculation with Arbuscular Mycorrhizal Fungi (AMF) and mineral fertilizer doses were used as experimental factors with the following combinations: (1) mycorrhization: control (without AMF); AMF applied to the plant root zone during seedling production; AMF applied to the plant root zone after seedlings were transferred to pots; (2) top dressing doses: basic dose (100%); 50% of the basic dose; 25% of the basic dose. The sweet pepper fruits were harvested during physiological maturity. AMF inoculation of the root zone resulted in high sweet pepper yields of good quality. In particular, mycorrhizal fungi applied to the root system during seedling production positively affected the pepper yield and biometric characteristics, with fruits of the thickest pericarp and the largest mass. In the experimental units with AMF, the reduction in the top dressing fertilizer dose by 50% and 75% did not cause a statistically significant decrease in the yield of peppers and did not result in a deterioration of the biometric characteristics of the plants and fruits or a reduction in the biological value of the fruits. Despite the reduction in top dressing dose by 50% and 75%, AMF contributed to the accumulation of similar amounts of phosphorus in the sweet pepper fruits. The top dressing dose of 50% applied during seedling production to the experimental units with mycorrhizal fungi resulted in a significant increase in the content of potassium, calcium, and magnesium. A significant increase in the amount of sodium in the fruits was noted in the experimental units with mycorrhizal fungi applied to the roots when the seedlings were transferred to pots. To summarize, the application of mycorrhizal fungi to the pepper root zone during seedling production is recommended because it has a positive effect on the yield and its quality. In the unit with mycorrhiza, a lower dose of mineral fertilizers did not result in a significant decrease in the yield of pepper fruits.

Keywords: arbuscular mycorrhizal fungi (AMF); mineral fertilizers; plant growth; yielding; nutrient quality; *Capsicum annuum* L.

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1. Introduction

The basic treatment that increases the productivity of crops is fertilizer application. However, of the total amount of nutrients introduced into the soil with mineral or natural

fertilizers, only a fraction is used by plants. The amounts of mineral fertilizer not taken up by crops lead to degradation of the soil environment. In order to maintain plant productivity and good soil conditions, modern agriculture and horticulture need new methods to reduce the adverse impact of the excessive use of mineral fertilizers and chemical products. Currently, a large role in this regard is attributed to arbuscular mycorrhizal fungi (AMF) [1]. AMF foster the availability and uptake of soil nutrients by plants. Mycorrhiza is a symbiotic relationship between certain soil fungi and the roots of most vascular plants. AM symbiosis is probably the most widely spread and positively affects approx. 80% of land plant species. Most vegetables create this kind of symbiosis as well [2], but it is not present in a sizable number of plant species (e.g., plants of the cabbage family). Those fungi are some of the most abundant organisms in the rhizosphere, living in symbiosis with more than 200,000 host plant species, including most crops [3,4]. They are of great agronomic importance as they improve soil properties and plant growth and yields [5]. The fungi increase the absorbent surface of the root system and contribute to a better supply of water and nutrients to plants, thus reducing mineral fertilizer use [6–9]. Thanks to a better supply of water and nutrients to plants, they improve plant growth and increase yield [10,11]. When colonized by mycorrhizal fungi, the root system has a greater possibility of absorbing nutrients, especially when the solubility and concentration of mineral compounds in the soil are low [12–15]. Thus, AMF increase the availability of such nutrients as phosphorus, nitrogen, and other macro- and micronutrients. According to Gnekow and Marschner [16], mycorrhiza increases the efficiency of phosphorus uptake by apple trees grown in phosphorus-poor soil, and in soils rich in this nutrient, it facilitates the uptake of zinc and copper. The use of AMF can effectively reduce the amounts of mineral fertilizers, especially phosphorous ones [17]. The use of AMF inoculation in plant cultivation can reduce the use of mineral fertilizers by up to 50% without lowering yield, but this estimate depends on the type of plants and on their resistance to stress conditions [18].

AMF inoculation also increases plant tolerance to the difficult growing conditions associated with stress-inducing factors, such as high soil salinity, water deficit or excess, high or low temperatures, acidification, soil contamination with heavy metals, and the presence of pathogenic fungi and nematodes [2,5,19]. Resistance to such stress factors brings economic benefits to plant production as a result of accelerated plant growth and increased yield [20–23].

Plants from the *Amaryllidaceae* (onion and leek), *Apiaceae* (carrot), *Asteraceae* (lettuce), *Cucurbitaceae* (cucumber), *Fabaceae* (bean), and *Solanaceae* (tomato and bell pepper) families possess a high dependence on mycorrhizal colonization [2]. Symbiosis with AMF is particularly essential for crops such as carrots, which have extremely short root hairs, to extend the depletion zone around the roots [24]. According to some authors, the best results in pepper cultivation can be obtained by inoculating plants in the early stage of seedling growth [25,26]. Early inoculation of peppers results in faster plant growth, earlier flowering and yielding, and higher fruit yields [4,27,28]. Mycorrhized red pepper plants set a larger number of fruits, which contain more dry matter. According to another report, a favourable effect of mycorrhiza on the accumulation of nutrients in red pepper fruits was observed [8]. Thanks to the use of AMF, plants are more effective in absorbing nutrients available in the rhizosphere, especially phosphorus, but also nitrogen, potassium, and micronutrients such as sulphur, zinc, copper, and manganese [4,27,29,30].

Pepper and sweet pepper (*Capsicum* spp.) have global economic importance, being grown in 116 countries on all continents. The Asian continent covers 67% of the total production of pepper and sweet pepper; the Americas are next (12.3%), followed by Africa (10.6%) and Europe (10.0%). The annual world production is 35.97 million tonnes, of which China produces 16.73 million tonnes, followed by Mexico (2.82 million tonnes) and Indonesia (2.77 million tonnes). In Europe, the largest pepper producers are Turkey (2.64 million tonnes) and Spain (1.47 million tonnes). In Poland, the annual production of pepper (mainly sweet pepper) is 161.4 thousand tones [31]. It is mainly grown in polytunnels and unheated greenhouses.

Sweet pepper is one of those plants that are important in human life. The interest in its cultivation is constantly increasing since its fruits are a rich source of minerals and vita-mins with antioxidant activity, including vitamin C, E, and provitamin A [32–34]. These compounds prevent cancer and cardiovascular diseases [35].

The following research hypothesis was adopted: AMF inoculation of the sweet pepper root system will make it possible to reduce the amount of mineral fertilizers without a significant reduction in fruit yield and quality. The purpose of the research was to determine the effect of AMF inoculation time and of mineral fertilizer doses (100%, 50%, and 25% of the basic dose) on selected plant growth parameters, fruit biometric features, and yield and on the accumulation of selected nutrients and minerals in the fruits. The research was carried out using the large-fruited 'Traviatta' cultivar.

2. Materials and Methods

2.1. Experimental Site, Growing Conditions, and Experimental Design

The experiment was conducted in an unheated greenhouse in central-eastern Poland (52°17′ N; 2°28′ E) during three growing seasons (2014–2016), with a completely random design and four replications.

The effect of two factors was investigated:

(A) Mycorrhization:

WM—control without mycorrhizal fungi;
MS—mycorrhizal fungi applied to the root zone in the seedling substrate;
MP—mycorrhizal fungi applied to the root zone during planting of seedlings into pots.

(B) Top dressing doses:

DP—basic dose per pot of 3.6 g N, 1.8 g P_2O_5, 5.4 g K_2O, 0.2 g MgO and 6.0 g SO_3;
DP50—50% of the basic dose;
DP25—25% of the basic dose.

Each dose of top dressing was divided into three parts and applied 4, 8, and 12 weeks after planting the seedlings into pots. The number of combinations in the experiment was 9, and the number of plots was 36. The plot area was 3 m^2. On each plot, there were 12 pots with pepper plants, with one plant in each pot.

Endotrophic AMF were used. Their producer and distributor was the Mycorrhizal Fungi Laboratory Mykoflor® (Końskowola, Poland). According to the information provided by the manufacturer, the mycorrhizal fungi used in pepper inoculation included the following species: *Rhizophagus intraradices* (syn. *Glomus intraradices)*, *Endogone mosseae* (syn. *Glomus mosseae)*, *Claroideoglomus claroideum* (syn. *Glomus claroideum)*, *Claroideoglomus etunicatum* (syn. *Glomus etunicatum)*, *Gigaspora margarita*, and *Entrophospora* sp. Mycorrhizal mycelium was grown on *Plantago lanceolata* L. on a sterile peat substrate. During the growing season, *Plantago lanceolata* L. was inoculated with spores of clean cultures, and when the growing period was over, the plants were dried and ground to a brown powder. It contained shredded roots of *Plantago lanceolata* L. and fungal spores [36].

The dose of AMF solution applied to one sweet pepper plant was 3 mL, or 100 propagation units. Each propagation unit can colonize one portion of the root system. The AMF solution was prepared by dissolving 1.5 g of dry inoculate in 450 mL of distilled water. According to the certificate presented by the manufacturer (Mycoflor®), 1 g of dry inoculate contains approximately 10,000 colony-forming units (CFUs) of live propagules. The amount of the solution prepared was enough for 150 plants, more than needed. At the first inoculation date (MS), i.e., at an early stage of pepper growth (during seedling production), 3 mL of AMF solution was applied at the time of transferring the seedlings from germination trays into smaller pots. The solution was applied directly to the root zone in the pot in which the seedling was produced. By 20–23 days after sowing the seeds, the plants were at the stage of fully developed cotyledons (BBCH 10 100). The second inoculation date (MP) was when the seedlings were transplanted into bigger pots of 9 L. Then, 60–64 days after sowing

the seeds, 3 mL of solution was applied directly to the pepper root ball. The plants were 20–25 cm tall with 1–2 flower buds visible (BBCH 51 501–52 502).

The plant used in the experiment was sweet pepper (*Capsicum annuum* L.) 'Traviatta F_1' cv., grown in plastic pots of 9 litres, filled with peat-based substrate for growing vegetables. Every year, new substrate was used to conduct the research. The 'Traviatta F_1' variety with blocky fruits was intended for cultivation under covers. The seed producer was Rijk Zwaan (De Lier, the Netherlands). The variety is highly resistant to soil-borne diseases. It is also highly tolerant to adverse environmental conditions.

Each year before the experiment, a substrate sample was collected to determine its pH, salinity, and macronutrient content. The substrate contained on average ($mg \cdot L^{-1}$): 122 N-NO_3; 18 N-NH_4; 63 P; 185 K; 1516 Ca; and 124 Mg. The value of pH in the H_2O was 5.42, which was lower than optimal. The amounts of nitrogen and magnesium were within the optimal content ($mg \cdot L^{-1}$): 100–175 N-NO_3 and 100–150 Mg. The content of other minerals was lower than optimal. According to Dobrzańska and Dobrzański [37], pepper should be grown on a substrate with a pH of 6–7, containing more than 7% of organic matter and with ($mg \cdot L^{-1}$): 175–250 P, 375–650 K, and 2000 Ca. The content of phosphorus, the potassium of the substrate, and its pH were increased to the lower limit of optimal values using FosDar 40 fertilizer containing 40% P_2O_5 and 10% CaO and applied at 640 g per cubic meter of the substrate. Additionally, potassium sulphate containing 51% K_2O and 45% SO_3 was applied at the amount of 460 g per cubic meter of the substrate. Each year, the pepper seeds were sown in the second part of February. The seedlings with developed cotyledons were transferred to plastic pot trays. Then, the seedling rhizosphere was inoculated with an aqueous solution of mycorrhiza (MS). In mid-May, the seedlings were planted into pots on plots located in a greenhouse and covered with black agrotextile. While planting the seedlings into pots, an aqueous solution of mycorrhizal fungi was applied to the root system (MP). The pepper plants were grown according to the agrotechnical recommendations [38].

The thermal and light conditions in the greenhouse were dependent on the weather. The average daily outdoor temperatures during pepper cultivation ranged between 13.7 and 20.5 °C in 2014; 12.3 and 21.0 °C in 2015; and 14.6 and 19.0 °C in 2016. From planting the seedlings to the end of the fruit harvest, the total insolation time was 1208 h in 2014, 1306 h in 2015, and 1330 h in 2016. The greenhouse was equipped with an automatic ventilation system (flaps in the roof and side walls), which made it possible to regulate the temperature inside during days with high sunlight. During the experiment, the temperature was maintained in the range of 21–28 °C during the day and 16–20 °C at night. For watering the plants, a drip irrigation system was used, with emitters supplying water to each pot.

2.2. Fruit Harvest and Measurements

Before fruit harvest, the SPAD leaf greenness index was measured using the Soil Plant Analysis Development portable apparatus SPAD-502 Plus (Konica Minolta Optics, Tokyo, Japan). The SPAD measurements were taken using five randomly selected plants from each experimental combination. Each measurement was replicated three times. The SPAD index has a close correlation with the state of the nitrogen nutrition of plants.

Each year, the harvest of pepper began in the second part of August and lasted until the beginning of October. During the harvest, the total yield ($kg \cdot m^{-2}$), the marketable yield ($kg \cdot m^{-2}$), the number of marketable fruits per plant, and the average mass of the marketable fruit (g) were determined. All the fruits harvested from the sweet pepper plants constituted the total yield. According to the Regulation of the European Commission No. 1455/99 [39], a marketable pepper yield should include whole fruits with peduncles; it should be healthy, clean, and fresh in appearance, free from pests and damage caused by pests, well-developed, and with the characteristics of the variety.

At the peak of the harvest (the third harvest), 10 fruits were sampled from each plot for laboratory testing. Before performing chemical analyses, the thickness of the pericarp was measured.

After the harvest, biometric measurements of the plants were made:

- Plant height (cm);
- Mass of the aboveground part and mass of the root system (g);
- Diameter of the stem at the base (mm).

Measurements were made on five randomly selected plants from each experimental combination.

The thickness of the pericarp and the diameter of the stem were measured with a digital caliper 20513 (Profix Ltd., Dobra, Poland) with an accuracy of 1 mm. Before weighing the root system, it was thoroughly rinsed from the substrate and dried. In order to determine the weight of the aboveground part and of the root system, the plant parts were weighed on a laboratory balance PRECISION SBS-LW-7500A (Steinberg Systems, Nowy Kisielin, Poland) with an accuracy of 1 g. The plant height was measured using a measuring tape with an accuracy of 1 mm.

2.3. Laboratory Analyses

Chemical analyses were carried out at the Laboratory of Structural Research and Natural Analysis of Siedlce University of Natural Sciences and Humanities. In the edible parts of the fruit, the following was determined:

- Dry matter content by the Polish Standard (PN-EN 12145) gravimetric method [40]. The seeds were removed from sweet pepper fruits; then, the shredded fruits were pre-dried. For this purpose, 50 g of each sample was prepared and dried at 60 °C to reach the humidity level of 8–10%. The samples were air-cooled for 1 h and weighed to an accuracy of 0.01 g. Then, 5 g of a sample was collected from the air-dried ground material and placed in a container with a lid. The samples were dried at 105 °C until the absolute difference between the dry matter values at two successive weight measurements was no more than 0.01%.
- Protein content by the classical Kjeldahl method using a conversion factor of 6.25, according to the AOAC procedure [41].
- Dried and ground sweet pepper fruit samples of 0.5 g were subjected to wet mineralization in concentrated H_2SO_4 using a catalyst. The obtained mineralizate was distilled in a Kjeltec System 1026 Distilling Unit (Tecator AB, Höganäs, Sweden). Then, the distillate was titrated with 0.1 N HCl until its colour changed from green to pink-purple. The protein content in the sample was calculated according to the formula:

$$pc = \frac{(A - B) \cdot C \cdot 1.4}{Ms} \cdot 6.25$$

where pc—protein content in the test sample (g·100 g^{-1} of dry matter); A—the amount of 0.1N HCl solution used for titration of the tested sample; B—the amount of 0.1N HCl solution used to titrate the blank sample; C—normal concentration of HCl = 0.1; Ms—mass of the tested sample (g); 1.4—the amount of nitrogen that corresponds to 1 cm^3 0.1 N HCl; and 6.25—conversion factor of nitrogen content in vegetables into protein content. Then, the protein content in the dry matter was converted to the protein content in the fresh matter of the pepper fruits.

- The content of total sugars and monosaccharides (g·100 g^{-1} of fresh matter) by the standard Luff–Schoorl method [42].
- L-ascorbic acid content. The determination was carried out according to Tillmans' method [43], which consists of the reduction of dyed 2.6-dichloroindophenol (2.6 DPIP) to a colourless leuco-compound by an acid solution of ascorbic acid. The fruit samples were homogenised; 10 g of the homogenate was weighed; and a 2% solution of oxalic acid was added to obtain a volume of 100 cm^3. The samples were transferred to a dark place for 15 min and then filtered. Then, 10 cm^3 of the filtrate was sampled and titrated with a solution of 2,6-dichloroindophenol until a slightly pink colour, persisting for about 10 s, was observed. The L-ascorbic acid content (AA, mg·100 g^{-1} of fresh matter) was calculated according to the formula:

$$AA = \frac{\text{volume of 2.6 DPIP used } (\text{cm}^3) \cdot \text{standard concentration of 2.6DPIP used} \cdot 100}{\text{volume of solution used for titration } (\text{cm}^3) \cdot \text{sample weight in 1 cm}^3 \text{ of the solution examined (g)}}$$

- Total polyphenol content using Folin–Ciocalteu reagent [44]. Twenty-five grams of fresh sweet pepper was extracted with methanol (80%) and defatted with petroleum ether. The solution (0.2 mL) was mixed with 6.8 mL of deionized water and 0.5 mL of 50% Folin–Ciocalteu reagent. After incubation for 3 min, 2.0 mL of 20% sodium carbonate (Na_2CO_3) was added, and water was added to the final volume of 10 mL. The absorbance of the dark blue product was measured at 725 nm (Lambda 25 spectrophotometer, PerkinElmer, Inc., Waltham, MA, USA). Gallic acid (Sigma-Aldrich) was used as the standard.
- Total acidity determined on the basis of citric acid by titration [45]. After malaxation, 25 g of sweet pepper fruits was added to 100 cm^3 of distilled water and heated to a boil. Then, the solution was cooled, the amount of distilled water was topped up to 250 cm^3 and left for 15 min. After filtration, 10 cm^3 of clear solution was measured, 2–3 drops of phenolphthalein were added, and 0.1 M was titrated with NaOH solution until it turned pink. Total acidity (Ta, g·100 g^{-1} of fresh matter) was calculated according to the formula:

$$\text{Ta} = \frac{\text{a} \cdot \text{n} \cdot K}{\text{c}} \cdot 100$$

  where a—the quantity of 0.1 M NaOH solution used for titration (cm); n—the molar of sodium hydroxide solution (0.1); *K*—the conversion of acidity to citric acid (0.064); and c—the mass of the pepper sample contained in the titrated solution.
- The content of macro- and micronutrients: phosphorus, potassium, calcium, magnesium, sodium, iron, copper, zinc, and manganese (mg·100 g^{-1} of dry matter). The content was determined by inductively coupled plasma optical emission spectrometry (ICP-OES), using the PerkinElmer Optima 8300 emission spectrometer (PerkinElmer, Inc., Waltham, MA, USA); the samples were subjected to microwave mineralization in 68% nitric acid (63.01 g·mol^{-1}) before the determination of the chemical element content. The content of macro- and microelements determined in dry matter was converted into the content in the fresh weight of the fruit and then converted into the amount of accumulated elements in the yield of pepper fruits harvested from an area of 1 m^2 according to the formula:

$$m_{Yt} = \frac{a \cdot Y_t}{100}$$

  where m_{Yt}—the amount of macro- or micronutrients accumulated in the total yield of sweet pepper fruits (g·m^{-2}); *a*—determined content of the element in the fresh weight of pepper fruits (mg·100 g^{-1} of fresh matter); and Y_t—total yield of pepper fruits (g·m^{-2}).

2.4. Statistical Analysis

The results of the studies were processed statistically using two-way ANOVA for the random design. The significance of differences between means was verified using Tukey's HSD test at the significance level of $p \leq 0.05$. Before performing the ANOVA test, assumptions about the normality of distributions and the uniformity of variance were checked. The Kolmogorov–Smirnov test was used to test the normality of distributions, and the Levene test was used to check the assumption of uniformity of variance in the subgroups. The tests showed that the assumptions of the ANOVA test were met at $p \leq 0.05$.

Statistical calculations were performed in Excel software using the authors' own algorithm based on the random mathematical model:

$$\text{Y}_{\text{ijl}} = \mu + A_{\text{i}} + B_{\text{j}} + AB_{\text{ij}} + \text{e}_{\text{ijl}} \quad (1)$$

where

y_{ijl}—the value of the examined characteristic; μ—population mean; A_i—the effect of the i-th level of factor A (mycorrhization); B_j—the effect of the j-th level of factor B (top dressing doses); AB_{ij}—interaction effect of the i-th level of factor A with the j-th level of factor B; and e_{ijl}—random effect [46].

The strength of relationships between:

- The yield parameters and the quality of the sweet pepper;
- The amount of macro- and micronutrients accumulated in the fruit yield per m^2;
- The selected elements of the nutritional value of the sweet pepper and the growth parameters of the plants and the value of the SPAD index were evaluated by calculating Pearson's correlation coefficients [46].

3. Results

3.1. Yield and Biometric Parameters of Sweet Pepper Fruits

Mycorrhizal inoculation contributed to an increase in the pepper parameters, significantly affecting the total and marketable fruit yields (Table 1). When introduced into the substrate during seedling production (MS), mycorrhizal fungi contributed to a statistically significant increase in the total and marketable yields, as compared to the control (WM) or to the pepper mycorrhized during the planting of the seedlings into pots (MP). Similar trends, but without statistically significant differences, were recorded for the number of marketable fruits per plant.

Table 1. Effect of AMF inoculation and top dressing doses on sweet pepper fruit yield and number of marketable fruits per m^2; on average across three years (2014–2016).

Mycorrhiza	Top Dressing	Total Yield ($kg \cdot m^{-2}$)	Marketable Yield ($kg \cdot m^{-2}$)	Number of Marketable Fruits ($No. \cdot m^{-2}$)
WM	DP	2.52 ± 0.41	2.27 ± 0.39	9.22 ± 1.55
	DP50	2.38 ± 0.43	2.15 ± 0.38	8.89 ± 1.45
	DP25	2.29 ± 0.36	2.05 ± 0.32	8.78 ± 1.54
MS	DP	2.84 ± 0.55	2.57 ± 0.53	9.67 ± 1.95
	DP50	2.61 ± 0.58	2.35 ± 0.52	9.33 ± 1.61
	DP25	2.52 ± 0.50	2.23 ± 0.47	9.22 ± 1.81
MP	DP	2.60 ± 0.56	2.36 ± 0.54	9.44 ± 2.17
	DP50	2.49 ± 0.54	2.25 ± 0.47	8.89 ± 1.56
	DP25	2.40 ± 0.45	2.14 ± 0.41	8.78 ± 1.23
WM		2.40 ± 0.41 a	2.16 ± 0.36 a	8.96 ± 1.53
MS		2.66 ± 0.56 b	2.38 ± 0.53 b	9.41 ± 1.73
MP		2.50 ± 0.52 a	2.25 ± 0.48 a	9.04 ± 1.65
	DP	2.65 ± 0.53 b	2.40 ± 0.51 b	9.44 ± 1.83
	DP50	2.49 ± 0.53 a	2.25 ± 0.47 a	9.04 ± 1.60
	DP25	2.40 ± 0.45 a	2.14 ± 0.41 a	8.93 ± 1.56

Source of variation	df	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$
Mycorrhiza	2	20.35	<0.01	0.11	17.45	<0.01	0.10	2.51	>0.05	NS
Top dressing	2	17.11	<0.01	0.12	10.97	<0.01	0.15	2.26	>0.05	NS
Interaction	4	0.99	>0.05	NS	1.32	>0.05	NS	0.22	>0.05	NS

Mean ± SD (n = 3) followed by different lowercase letters in columns differ significantly at $p \leq 0.05$; NS—not significant, df—degrees of freedom, *F*—F-distribution, *P*—probability, $HSD_{0.05}$—honestly significant difference. WM—control without mycorrhizal fungi, MS—mycorrhizal fungi applied to the root zone in the seedling substrate, MP—mycorrhizal fungi applied to the root zone during planting seedlings into pots; top dressing doses: DP—basic dose per pot of 3.6 g N, 1.8 g P_2O_5, 5.4 g K_2O, 0.2 g MgO, and 6.0 g SO_3, DP50—50% of the basic dose, DP25—25% of the basic dose.

Mycorrhization increased the biometric characteristics of the fruits compared to the control (Table 2). The fruits of the plants mycorrhized during seedling production (MS) had the thickest pericarp and the highest mass, with both values being significantly higher than those for the non-mycorrhized plants (WM), but with no significant difference between the MS and MP fruits.

Table 2. Biometric characteristics of sweet pepper marketable fruits; on average across three years (2014–2016).

Mycorrhiza	Top Dressing	Pericarp Thickness (mm)			Fruit Weight (g)		
WM	DP	6.06 ± 0.58			246.5 ± 12.14		
	DP50	6.01 ± 0.63			241.4 ± 15.62		
	DP25	5.79 ± 0.56			235.6 ± 18.76		
MS	DP	6.55 ± 0.62			266.2 ± 17.76		
	DP50	6.33 ± 0.65			250.7 ± 20.11		
	DP25	6.12 ± 0.27			241.6 ± 17.63		
MP	DP	6.18 ± 0.56			250.2 ± 11.27		
	DP50	5.88 ± 0.56			252.5 ± 12.20		
	DP25	6.02 ± 0.49			243.4 ± 19.87		
WM		5.95 ± 0.61 a			241.2 ± 16.36 a		
MS		6.33 ± 0.57 b			252.8 ± 20.45 b		
MP		6.03 ± 0.55 ab			248.7 ± 15.88 ab		
	DP	6.26 ± 0.62			254.3 ± 16.43 b		
	DP50	6.07 ± 0.60			248.2 ± 17.41 ab		
	DP25	5.98 ± 0.49			240.2 ± 19.42 a		
Source of variation	df	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$
Mycorrhiza	2	4.30	0.04	0.37	7.68	<0.01	8.07
Top dressing	2	1.67	>0.05	NS	7.36	<0.01	9.84
Interaction	4	1.00	>0.05	NS	1.82	>0.05	NS

Explanations: see Table 1.

Reducing the fertilizer top dressing doses by 50% (DP50) and 75% (DP25) resulted in a significant decrease in total and marketable yields (Table 1). The weight of a marketable fruit also decreased (Table 2), with a significantly lower value in response to top dressing DP25.

3.2. Chlorophyll Content (SPAD Index) and Biometric Characteristics of Sweet Pepper Plants

The SPAD index was significantly dependent on the mycorrhization and top dressing doses (Table 3). For plants without mycorrhizal inoculation (WM), the lowest top dressing rate (DP 25) resulted in a significant decrease in the SPAD index compared to the effects of DP and DP50. The pepper mycorrhized during seedling production (MS) and treated with DP50 and DP25 top dressing had a significantly lower SPAD index than the plants treated with DP. For the pepper mycorrhized during the planting of the seedlings into pots (MP), the different top dressing doses did not cause significant changes in the SPAD index.

Table 3. SPAD leaf greenness index and biometric characteristics of sweet pepper plants; on average across three years (2014–2016).

Mycorrhiza	Top Dressing	SPAD			Plant Height (cm)			Stalk Diameter (mm)			Weight of the Aerial Part (g·plant^{-1})			Weight of the Root System (g·plant^{-1})		
WM	DP	52.7 ± 3.1 b			71.3 ± 2.4			13.4 ± 1.6			551 ± 34			225 ± 19		
	DP50	52.8 ± 4.0 b			67.0 ± 2.9			13.6 ± 1.3			520 ± 46			247 ± 21		
	DP25	49.1 ± 5.9 a			64.8 ± 2.9			14.6 ± 1.1			494 ± 51			249 ± 21		
MS	DP	54.7 ± 3.1 b			76.5 ± 2.0			14.8 ± 1.4			617 ± 48			243 ± 23		
	DP50	51.2 ± 4.4 a			73.5 ± 3.0			15.2 ± 1.5			592 ± 34			264 ± 21		
	DP25	51.1 ± 5.6 a			69.9 ± 2.2			15.9 ± 1.4			569 ± 56			273 ± 21		
MP	DP	52.1 ± 2.7 a			73.5 ± 2.6			13.8 ± 2.1			581 ± 48			229 ± 10		
	DP50	50.3 ± 4.0 a			69.9 ± 2.4			14.6 ± 1.3			560 ± 41			244 ± 19		
	DP25	51.5 ± 3.6 a			67.5 ± 3.2			15.1 ± 1.8			522 ± 41			250 ± 22		
WM		51.6 ± 4.8			67.7 ± 3.8 a			13.9 ± 1.4 a			521 ± 50 a			240 ± 23 a		
MS		52.3 ± 4.8			73.3 ± 3.6 c			15.3 ± 1.5 c			593 ± 51 c			260 ± 25 b		
MP		51.3 ± 3.6			70.3 ± 3.7 b			14.5 ± 1.9 b			554 ± 50 b			241 ± 20 a		
	DP	53.2 ± 3.2			73.7 ± 3.2 c			14.0 ± 1.8 a			583 ± 51 c			233 ± 20 a		
	DP50	51.4 ± 4.3			70.1 ± 3.9 b			14.5 ± 1.5 b			557 ± 50 b			252 ± 22 b		
	DP25	50.6 ± 5.2			67.4 ± 3.5 a			15.2 ± 1.6 c			528 ± 59 a			257 ± 24 b		
Source of variation	df	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$
Mycorrhiza	2	1.32	>0.05	NS	47.13	<0.01	1.6	43.15	<0.01	0.4	96.37	<0.01	14	28.43	<0.01	8
Top dressing	2	2.74	>0.05	NS	42.56	<0.01	1.8	20.23	<0.01	0.5	27.17	<0.01	20	16.32	<0.01	12
Interaction	4	4.26	<0.01	2.7	0.85	>0.05	NS	0.93	>0.05	NS	0.72	>0.05	NS	0.78	>0.05	NS

Explanations: see Table 1.

Mycorrhizal fungi applied during the production of seedlings (MS) in the most favourable way affected the height, stem diameter, and mass of the aboveground part of the plants (Table 3). The values of those parameters were significantly lower for the plants mycorrhized during the planting of the seedlings into pots (MP) and the significantly lowest for the control plants (WM). Inoculation during the production of seedlings (MS) had the most beneficial effect on the mass of the root system. The non-mycorrhized plants (WM) and those inoculated during the planting of the pepper into pots (MP) were of significantly lower mass than the plants mycorrhized during seedling production (MS).

With the reduction in the top dressing dose, the height of the plants and the mass of the aboveground part decreased significantly, while a significant increase in the diameter of the stem was recorded. Lower top dressing doses resulted in a significant increase in the mass of roots.

A significant positive correlation was found between the total yield, the marketable yield, and the number of marketable fruits per plant on the one hand and the mass of the root system and the diameter of the stem on the other (Table 4). The greater mass of the aboveground part was a result of a larger assimilation surface and a larger nutrient production, which also positively affected the yield and number of fruits. A more extensive root system was more effective in supplying the plants with the water and nutrients necessary for intensive fruit growth (Table 4). Mycorrhizal fungi applied during seedling production (MS) positively affected the mass of the aboveground part and of the root system. The same application also contributed to the growth of the fruits, as evidenced in a statistically significant way by the positive correlation coefficients between the mass of the aboveground part and the mass of the root system on the one hand and the mass of the fruit on the other.

Table 4. Linear correlation coefficients (n = 81) between yield parameters and the quality of sweet pepper, and growth parameters of plants and the value of SPAD index.

Growth Parameters	Total Yield	Marketable Yield	Number of Marketable Fruits	Fruit Weight	Pericarp Thickness
Weight of the aerial part	0.0406	0.0479	−0.0577	0.2900 **	0.0718
Weight of the root system	0.6326 **	0.6087 **	0.5693 **	0.2741 *	0.0284
Plant height	−0.1886	0.1968	−0.2299 *	0.0274	0.3110 **
Stalk diameter	0.2857 **	0.2750 *	0.3504 **	−0.1437	0.3863 **
SPAD	−0.0870	−0.0836	0.1572	0.1155	0.0954

Significance: $p \leq 0.05$ * (0.2172); $p \leq 0.01$ ** (0.2830).

Mycorrhizal fungi applied during seedling production (MS) stimulated the growth of the root system and thus indirectly contributed to an increase in pepper yield. The correlation coefficients indicated numerous relationships between the pepper yield and growth parameters (Table 4). The yield of the pepper was significantly correlated with the uptake of water and nutrients from the soil and their transfer to the aboveground part. A significant negative correlation between the height of the plants and the number of marketable fruits per plant indicated that the conditions were conducive to intensive vegetative growth, but they limited the flowering and fruit set (Table 4). On the other hand, the height of the plants and stem diameter were positively correlated with pericarp thickness; thus, the stem diameter determined the quality of the fruits. However, the correlation index did not confirm the relationship between the parameters of the fruit yield (average fruit mass and pericarp thickness) on the one hand and the mass of the aboveground part and the value of the SPAD index on the other (Table 4).

3.3. The Amount of Macro- and Micronutrients Accumulated in the Yield of Sweet Pepper

In the fruits collected from an area of 1 m^2, the sweet pepper plants accumulated an average of 583 g of phosphorus, 4654 g of potassium, 286 g of calcium, 256 g of magnesium, and 19 g of sodium (Table 5). The content of macronutrients in the pepper fruits was significantly dependent on the plant mycorrhization and on the top dressing doses. Compared

to the full dose (DP), the reduced top dressing doses of DP50 and DP25 applied to the non-mycorrhized pepper (WM) resulted in a statistically significant decrease in phosphorus content. For the inoculated plants, when the top dressing was reduced to DP50 or DP25, no statistically significant reduction in phosphorus content was observed.

Table 5. The amount of macronutrients accumulated in the total yield of sweet pepper fruits; on average across three years (2014–2016).

Mycorrhiza	Top Dressing	P			K			Ca ($g \cdot m^{-2}$)			Mg			Na		
	DP	681 ± 115 b			4502 ± 832 a			298 ± 29 b			266 ± 47 b			19.0 ± 2.4 a		
WM	DP50	501 ± 97 a			4419 ± 1688 a			264 ± 46 a			246 ± 57 a			17.6 ± 5.0 a		
	DP25	517 ± 76 a			4065 ± 982 a			260 ± 31 a			231 ± 46 a			18.6 ± 4.9 a		
	DP	595 ± 99 a			4769 ± 1289 a			307 ± 48 ab			275 ± 54 b			19.0 ± 3.8 a		
MS	DP50	638 ± 179 a			5652 ± 1824 b			324 ± 65 b			282 ± 75 b			20.6 ± 4.5 a		
	DP25	570 ± 55 a			4591 ± 1244 a			282 ± 21 a			254 ± 54 a			19.9 ± 4.4 a		
	DP	563 ± 111 a			4514 ± 1564 a			272 ± 41 a			261 ± 59 b			15.7 ± 3.6 a		
MP	DP50	589 ± 169 a			4580 ± 1956 a			300 ± 43 a			252 ± 58 ab			22.6 ± 4.9 b		
	DP25	597 ± 92 a			4797 ± 1837 a			271 ± 43 a			240 ± 42 a			17.8 ± 4.1 a		
WM		566 ± 127			4329 ± 1240 a			274 ± 40 a			248 ± 52 a			18.4 ± 4.3		
MS		601 ± 125			5004 ± 1886 b			304 ± 56 b			270 ± 67 b			19.8 ± 4,3		
MP		583 ± 129			4630 ± 1797 ab			281 ± 48 a			251 ± 58 a			18.7 ± 5.1		
	DP	613 ± 119			4595 ± 1271			292 ± 42			268 ± 54 b			17.9 ± 3.7		
	DP50	576 ± 163			4884 ± 1277			296 ± 54			260 ± 63 b			20.3 ± 5.2		
	DP25	561 ± 83			4484 ± 1434			271 ± 34			241 ± 49 a			18.8 ± 4.6		
Source of variation	df	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$
Mycorrhiza	2	0.79	>0.05	NS	5.90	0.02	526	7.70	<0.01	22	8.64	<0.01	16	3.70	>0.05	NS
Top dressing	2	1.09	>0.05	NS	0.88	>0.05	NS	2.20	>0.05	NS	9.73	<0.01	16	1.73	>0.05	NS
Interaction	4	8.70	<0.01	87	4.21	0.01	678	4.75	<0.01	30	4.58	<0.01	13	8.45	<0.01	2.8

Explanations: see Table 1.

The non-inoculated plants (WM) accumulated less potassium in the total fruit yield than the inoculated ones. On the MS plots, with fungal application during seedling production, the use of DP and DP25 resulted in a significant decrease in the fruit potassium content compared to DP50. For the same type of fungal application, the reduction in top dressing to DP50 and DP25 resulted in a decrease in potassium amounts in the fruit yield, with an increase on the MP plots, but the differences were not statistically significant.

On the WM plots, the lowering of the top dressing rates to 50% and to 25% significantly reduced the amounts of calcium and magnesium in the total yield. On the MS plots, the most calcium and magnesium was recorded in the fruits of the plants treated with DP50 top dressing. As a response to the basic dose (DP), the amount of calcium and magnesium was lower, but the difference was not statistically significant. A significant decrease in the amount of these chemical elements was found after the use of DP25. On the MP plots, the top dressing doses did not cause significant changes in the amount of accumulated calcium, but significantly differentiated the magnesium content. The fruits of the plants treated with DP top dressing contained the greatest amounts of magnesium, with the significantly smallest value recorded on the DP25 plots.

No statistically significant differences in total yield sodium content were observed between the non-inoculated plants (MS) and those inoculated during seedling production (MS). In the case of the pepper inoculated during the planting of the seedlings into pots (MP), the amount of sodium in the fruits from the plants treated with half the top dressing dose (DP50) was significantly higher than that from the plants treated with the full dose (DP) and with the dose reduced to 25% (DP25).

Compared to the non-inoculated plants, mycorrhizal fungi contributed to an increase in the micronutrient content in the fruits from an area of 1 m^2 (Table 6). The most micronutrients in the total yield of fruits were found when the plants were inoculated during seedling production (MS).

On the plots without mycorrhizal fungi (WM), the reduction in the top dressing dose resulted in a lower iron content in the fruits. Significant differences were found between the effects of the DP and DP25 doses. Mycorrhizal fungi used at the seedling production stage (MS) and the DP50 dose contributed to the accumulation of the largest amount of iron and manganese in the fruit yield. The fungi applied during the planting of the peppers

into pots (MP) and the DP25 mineral fertilizer dose contributed to the accumulation of the largest amount of iron and zinc.

Table 6. The amount of micronutrients accumulated in the total yield of sweet pepper fruits; on average across three years (2014–2016).

Mycorrhiza	Top Dressing	Fe	Mn	Cu	Zn
			(mg·m^{-2})		
WM	DP	5.75 ± 0.85 b	2.34 ± 0.48 a	1.12 ± 0.15	6.10 ± 1.47 a
	DP50	5.00 ± 0.89 ab	2.03 ± 0.58 a	1.11 ± 0.26	6.30 ± 1.74 a
	DP25	4.77 ± 0.83 a	1.91 ± 0.35 a	1.17 ± 0.39	5.95 ± 1.35 a
MS	DP	5.53 ± 0.86 a	2.35 ± 0.38 ab	1.27 ± 0.23	7.30 ± 1.07 a
	DP50	6.29 ± 1.66 b	2.94 ± 0.34 b	1.37 ± 0.27	8.46 ± 1.99 a
	DP25	5.60 ± 0.72 a	2.22 ± 0.30 a	1.28 ± 0.21	8.22 ± 1.16 a
MP	DP	5.39 ± 1.52 a	2.39 ± 0.60 a	1.16 ± 0.16	6.59 ± 2.13 a
	DP50	5.41 ± 1.46 a	2.33 ± 0.43 a	1.28 ± 0.29	6.87 ± 2.19 a
	DP25	6.10 ± 0.90 b	2.33 ± 0.70 a	1.23 ± 015	8.32 ± 2.15 b
WM		5.17 ± 0.95 a	2.09 ± 0.55 a	1.13 ± 0.28 a	6.12 ± 1.54 a
MS		5.81 ± 1.25 b	2.50 ± 0.78 b	1.31 ± 0.24 b	7.99 ± 2.01 b
MP		5.63 ± 1.36 b	2.35 ± 0.59 b	1.22 ± 0.22 ab	7.26 ± 2.18 b
	DP	5.56 ± 1.13	2.36 ± 0.49	1.18 ± 0.20	6.66 ± 1.69 a
	DP50	5.57 ± 1.41	2.43 ± 0.88	1.26 ± 0.29	7.21 ± 2.20 ab
	DP25	5.49 ± 0.98	2.15 ± 0.52	1.23 ± 0.27	7.49 ± 1.79 b

Source of variation	df	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$
Mycorrhiza	2	14.64	<0.01	0.32	18.77	<0.01	0.18	4.25	0.04	0.16	23.56	<0.01	0.74
Top dressing	2	0.07	>0.05	NS	1.31	>0.05	NS	0.73	>0.05	NS	4.30	0.04	0.77
Interaction	4	13.46	<0.01	0.56	2.86	0.04	0.60	0.88	>0.05	NS	5.57	<0.01	0.97

Explanations: see Table 1.

The sodium accumulation was strongly positively correlated with the mass of the aboveground part; the accumulation of potassium, magnesium, and iron with the mass of the root system; the potassium, calcium, magnesium, manganese, copper, and zinc with the stalk diameter; and the potassium with SPAD. A significant positive correlation was also found between the sodium accumulation and plant height and SPAD, as well as between phosphorus and iron accumulation and stalk diameter (Table 7).

Table 7. Linear correlation coefficients (n = 81) between the amount of macro- and micronutrients accumulated in the fruit yield per m^2, and growth parameters of plants and the value of SPAD index.

Growth Parameters	P	K	Ca	Mg	Na
Weight of the aerial part	0.0472	−0.1509	0.0848	−0.1899	0.3722 **
Weight of the root system	0.1366	0.3594 **	0.1939	0.2977 **	0.2006
Plant height	−0.0777	−0.1257	0.0276	−0.0299	−0.2197*
Stalk diameter	0.2445 *	0.4801 **	0.4122 **	0.5607 **	−0.1746
SPAD	0.0707	0.4801 **	0.0962	0.0791	0.2753 *
	Fe	**Mn**	**Cu**		**Zn**
Weight of the aerial part	0.1292	−0.0401	−0.0580		0.0472
Weight of the root system	0.3651 **	0.2107	−0.2096		0.4803 **
Plant height	−0.1303	0.0207	0.1715		−0.1002
Stalk diameter	0.2440 *	0.3866 **	0.3166 **		0.3970 **
SPAD	0.0406	−0.0716	0.0262		−0.0970

Significance: $p \leq 0.05$ * (0.2172); $p \leq 0.01$ ** (0.2830).

3.4. Dry Matter, Protein, Sugars, L-Ascorbic Acid, and Polyphenols Content and Total Acidity

The content of dry matter, protein, and polyphenols in the pepper fruits was significantly dependent on mycorrhization and the dose of top dressing (Table 8).

Table 8. Content of selected elements of nutritional value in sweet pepper fruits; on average across three years (2014–2016).

Mycorrhiza	Top Dressing	Dry Matter (%)	Protein (g·100 g^{-1} FM)	Total Sugars (g·100 g^{-1} FM)	Monosaccharides (g·100 g^{-1} FM)	L-Ascorbic Acid (mg·100 g^{-1} FM)	Total Acidity (g·100 g^{-1}św.m)	Polyphenols (mg·100 g^{-1} FM)
WM	DP	6.61 ± 0.29 ab	1.12 ± 0.11 b	3.47 ± 0.24	2.41 ± 0.05	122.07 ± 4.98	0.34 ± 0.01	50.99 ± 8.86 b
	DP50	6.94 ± 0.59 b	1.02 ± 0.10 a	3.43 ± 0.25	2.42 ± 0.07	119.90 ± 4.29	0.33 ± 0.02	49.90 ± 9.59 ab
	DP25	6.50 ± 0.47 a	1.08 ± 0.13 ab	3.44 ± 0.24	2.41 ± 0.05	126.46 ± 7.72	0.35 ± 0.01	43.77 ± 8.57 a
MS	DP	6.67 ± 0.54 ab	1.09 ± 0.10 a	3.46 ± 0.26	2.41 ± 0.04	123.70 ± 7.83	0.34 ± 0.01	47.37 ± 4.18 a
	DP50	6.94 ± 0.53 b	1.12 ± 0.12 a	3.45 ± 0.20	2.40 ± 0.05	123.38 ± 4.63	0.34 ± 0.02	48.50 ± 7.59 a
	DP25	6.57 ± 0.27 a	1.11 ± 0.04 a	3.33 ± 0.30	2.39 ± 0.07	121.20 ± 5.56	0.34 ± 0.02	46.75 ± 6.90 a
MP	DP	6.38 ± 0.33 a	1.05 ± 0.13 a	3.54 ± 0.20	2.41 ± 0.04	125.44 ± 6.52	0.35 ± 0.02	44.10 ± 9.50 a
	DP50	6.86 ± 0.48 b	1.13 ± 0.11 a	3.51 ± 0.21	2.42 ± 0.05	119.27 ± 8.18	0.33 ± 0.02	50.51 ± 8.26 a
	DP25	6.86 ± 0.31 b	1.13 ± 0.09 a	3.52 ± 0.21	2.48 ± 0.11	120.12 ± 8.05	0.34 ± 0.03	49.72 ± 9.63 a
WM		6.68 ± 0.50	1.07 ± 0.12	3.44 ± 0.25 ab	2.41 ± 0.07	123 ± 6.46	0.34 ± 0.02	48.2 ± 11.74
MS		6.73 ± 0.49	1.10 ± 0.10	3.42 ± 0.26 a	2.40 ± 0.06	123 ± 6.26	0.34 ± 0.02	47.5 ± 6.44
MP		6.70 ± 0.44	1.10 ± 0.12	3.52 ± 0.21 b	2.44 ± 0.08	122 ± 7.78	0.34 ± 0.03	48.1 ± 9.59
	DP	6.55 ± 0.42	1.08 ± 0.12	3.50 ± 0.24	2.41 ± 0.06	124 ± 6.69	0.34 ± 0.02	47.5 ± 8.36
	DP50	6.91 ± 0.54	1.09 ± 0.12	3.46 ± 0.22	2.41 ± 0.06	121 ± 6.68	0.33 ± 0.02	49.6 ± 10.07
	DP25	6.65 ± 0.39	1.11 ± 0.10	3.43 ± 0.27	2.43 ± 0.09	123 ± 8.07	0.34 ± 0.02	46.8 ± 8.78

Source of variation	df	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$	*F*	*P*	$HSD_{0.05}$
Mycorrhiza	2	0.14	>0.05	NS	0.51	>0.05	NS	6.61	0.01	0.09	1.60	>0.05	NS	0.36	>0.05	NS	0.22	>0.05	NS	0.07	>0.05	NS
Top dressing	2	3.71	>0.05	NS	0.39	>0.05	NS	0.37	>0.05	NS	0.33	>0.05	NS	1.60	>0.05	NS	1.39	>0.05	NS	0.76	>0.05	NS
Interaction	4	3.34	0.03	0.36	2.88	0.04	0.11	2.12	>0.05	NS	1.04	>0.05	NS	2.41	>0.05	NS	1.74	>0.05	NS	3.59	0.02	6.52

FM—fresh matter; other explanations: see Table 1.

Lower top dressing doses on the WM and MS plots reduced the fruit dry matter content. A significant difference was found between the effects of the DP25 and DP50 doses. On the MP plots, the reduced top dressing doses of DP50 and DP25 resulted in a significant increase in fruit dry matter content, compared to that found in response to the full dose (DP). A significant decrease in protein content was found on the WM plots after the application of the DP50 top dressing dose, compared to the effect of DP.

Mycorrhization affected the total sugar content of the pepper fruits. The largest amounts were recorded in the fruits collected from the plants inoculated during the transfer of seedlings to pots (MP). A significantly lower content of total sugars was recorded in the fruits of the plants inoculated during seedling production (MS). The mycorrhization of the plants and the differentiated top dressing doses did not cause significant changes in the content of reducing sugars and L-ascorbic acid or in the total acidity of the fruits.

Significant differences in polyphenol content were found in the fruits from the non-inoculated plants (WM). Most of these compounds were found after the application of the basic top dressing dose (DP). Lower doses decreased the content of polyphenols. A significant difference was found between the DP and DP25 effects.

The correlation indexes indicated significant relationships between the nutritional value on the one hand and the plant growth parameters and the SPAD index on the other (Table 9). The dry matter and polyphenol amounts were significantly positively correlated with the mass of the aboveground part and stem diameter. Dry matter content was also positively correlated with root system mass. The plant parameters indicated favourable growing conditions (well-developed root system, large stem diameter conducive to the transport of water and nutrients to the aboveground part, and large assimilation apparatus of the aboveground part). In effect, the dry matter and polyphenol content in the pepper fruits increased. A significant positive correlation between polyphenol content and the SPAD index also indicated a relationship between the efficiency of photosynthesis resulting from the content of chlorophyll in plants and the production and accumulation of phenolic compounds in the fruits.

Table 9. Linear correlation coefficients (n = 81) between selected elements of the nutritional value of sweet pepper, and growth parameters of plants and the value of SPAD index.

Growth Parameters	Dry Matter	Protein	Total Sugars	Monosacchar.	L-Ascorbic Acid	Total Acidity	Polyphenols
Weight of the aerial part	0.2563 *	−0.0703	0.1123	−0.2006	0.0724	−0.2000	0.3705 **
Weight of the root system	0.2807 *	0.0500	0.0940	−0.1355	−0.2450*	0.1635	0.0974
Plant height	−0.1358	−0.0634	0.2034	−0.0126	0.1940	−0.0026	−0.1503
Stalk diameter	0.3458 **	0.4036 **	0.1183	0.2067	−0.0955	0.3663 **	0.4400 **
SPAD	0.1815	−0.1096	0.2048	0.1182	0.1792	0.1318	0.3273 **

Significance: $p \leq 0.05$ * (0.2172); $p \leq 0.01$ ** (0.2830).

The protein content and acidity were positively correlated with stem diameter, which indicated that a well-developed conductive system, facilitating the transport of nitrogen and minerals from the soil to the aboveground part, increased the accumulation of proteins and organic acids in the pepper fruits.

4. Discussion

The application of mycorrhizal fungi increases yield quality and quantity and improves the growth and nutrition of plants. Mikiciuk et al. [47] found that plant growth was directly related to the degree of root colonization by AMF. This may be due to the influence of microorganisms, including mycorrhizal fungi, on the physiological characteristics of plants (the content of chlorophylls a and b in plant leaves), which translates into better growth and higher yield. In the present research, mycorrhiza contributed to an increase in the total and marketable yield compared to that of sweet pepper grown without mycorrhiza. Mycorrhization during the production of the seedlings had a better yield effect than the application of fungi during the planting of the seedlings into pots. As a result of AMF

inoculation during seedling production (MS), a significant increase in total yield (by over 10%) was noted. Compared to the control plants, without inoculation (WM), the marketable fruit yield increased by 6.9% as a result of mycorrhizal fungi being applied to the plants in pots (MP) and by 11.9% when the seedlings were inoculated (MS). Faisal et al. [48] found a positive effect of AM fungi on the fruit yield of Ancho and Mirasol, two pepper cultivars. Similarly, Marihal et al. [49] reported that inoculation with AMF increased the yield of pepper grown in field conditions. Sharif and Classen [50] reported that inoculation of AMF plants improved the fruiting of peppers. This was due to an increase in the concentration of phosphorus in the soil solution and the faster uptake of this element through a larger absorbent surface of the root system due to mycelium hyphae. Thanks to this, it was possible to limit the treatment of plants with phosphorus. In addition, early mycorrhization increases the resistance of the root system to soil pathogens and improves plant health, positively affecting the growth and yield of plants [25]. The increase in pepper yield can also be explained by the impact of mycorrhizal fungi on plant health and on their resistance to biotic and abiotic stress. This has been confirmed by the research of many authors [51–56]. Candido et al. [57] report that inoculation of seedlings with materials containing AMF is the most promising method applied to horticultural crops. Reduced seedling mortality as well as greater uniformity of plant growth and yield were the result of AMF inoculation, although the effects were largely dependent on the mutual match between the fungus and the host plant species [58,59].

According to Zhu et al. [60], better root growth results from the effect of microorganisms on the synthesis of the phytohormones (e.g., IAA) responsible for elongation growth. This may explain the effect of mycorrhiza on the greater weight of the pepper root system in the present research.

Using AMF during the 9-leaf stage (BBCH 19), Iula et al. [61] found a significantly higher yield of tomato fresh and dry matter compared to control plants grown without AMF. In the present research, mycorrhization of the pepper root system in the early stage of growth (MS) resulted in a significant increase in stem diameter by 10.1%, plant height by 8.3%, and the fresh mass of aboveground parts by 13.82% and of the root system by 83% compared to control plants grown without AMF. As a result of the inoculation of the seedlings when they were transferred to pots (MP), the plants were taller by 3.8% and the mass of aboveground parts increased by 6.33% compared to non-mycorrhized pepper (WM). According to Stewart et al. [62], mycorrhizal inoculation increased the growth of strawberry seedlings by 50% compared to a control.

In the present studies, compared to the non-inoculated control, 0.8% to 5% more fruits from the plants inoculated with AMF were collected. However, the differences were not statistically significant. Faisal et al. [48] and Román-García [63] found a significant effect of AM fungi on an increase in the number of fruits of two pepper cultivars, Ancho and Mirasol, by 47% and 46%, respectively. Additionally, mycorrhization of zucchini squash (*Cucurbita pepo* L. cv. Grezini) with *Glomus intraradices* and *Trichoderma atroviride* fungi resulted in a significant increase in the number of fruits, with their significantly higher average mass, which consequently resulted in a significantly higher total yield, compared to a control without mycorrhization [64].

In the present research, the fruits collected from mycorrhized plants had a thicker pericarp, and their average mass was higher compared to fruits collected from non-mycorrhized plants. Castillo et al. [3] and Ortas et al. [65] report that the advantage of hot pepper and sweet pepper inoculation with mycorrhizal fungi is their early flowering and fruiting as well as the increased fruit yield and quality [4,66]. After the mycorrhization of tomato seedlings with fungi of the *Glomus genus*, Dubova et al. [7] collected fruits with a higher mass and more dry matter compared to non-mycorrhized plants.

In the present research, despite a lack of significant differences, a slightly higher SPAD index was recorded for plants whose root systems were inoculated with AMF during the production of seedlings (MS), compared to the control plants grown without AMF.

Mycorrhized pepper, tomato, and zucchini plants had significantly higher SPAD than non-mycorrhized plants [64]. In a similar way, Majkowska-Gadomska et al. [67] found a positive effect of mycorrhizal inoculation on tomato yield and nutritional status, which was determined on the basis of the leaf greenness index (SPAD). The higher SPAD index of mycorrhized plants compared to non-mycorrhized plants is due to better plant nutritional status. The hyphae of mycorrhiza form a coat covering the roots, thus facilitating the uptake of nutrients by plants and their better nutrition. This mechanism makes it possible to reduce mineral fertilizer doses.

In the present research, lower top dressing doses of 50% and 25% applied to mycorrhized plants did not contribute to reducing the amount of phosphorus accumulated in the fruit yield. On the other hand, the fruits from plants without mycorrhizal inoculation and with decreased doses of top dressing accumulated significantly less of this element. Increased levels of phosphorus and zinc in the shoots of inoculated pepper plants were also observed by Ortas et al. [65]. Additionally, according to Sharif and Claassen [50], in soils with low levels of phosphorus, the hyphae were more efficient in its absorption than the root surface. Pereira et al. [10] and Sharif and Claassen [50] observed that in soil with low phosphorus content, plant inoculation with AMF increased the carbohydrate production, which was associated with increased phosphorus absorption.

High concentrations (in stress-free conditions) of phosphorus can inhibit root fungal colonization, while its low concentrations (stress conditions) promote it [68]. Sensoy et al. [59] found no significant effect of AMF on pepper phosphorus content, but the authors speculated that the reason for this was the appropriate level of phosphorus in the substrate. Phosphorus uptake is directly related to plant growth, and when it reaches an adequate concentration level in the soil, i.e., the plant is not under nutritional stress, AM colonization is inhibited by autoregulated symbiosis mechanisms, making AM fungi unnecessary and incompatible with stress conditions [69]. Allen and Shachar-Hill [70] found that the use of mycorrhizal fungi increased the uptake of not only phosphorus but also potassium, sulphur, magnesium, copper, zinc, and iron by the host plant.

In the present studies, when the pepper plants inoculated with mycorrhizal fungi were treated with the dose of top dressing reduced by half, better results in the accumulation of potassium were recorded than those found in response to the full dose. It is worth emphasizing that an even further reduction in the top dressing dose to the level of 25% did not cause a decrease in the potassium accumulated in the yield when compared to the full dose of top dressing.

Mycorrhizal fungi applied during seedling production as well as to the substrate in pots resulted in a significant increase in zinc accumulation in the total yield of fruits. Additionally, studies by Allen and Shachar-Hill [70] and Jansa et al. [71] confirmed the effect of AMF on increasing zinc uptake.

In the present research, a beneficial effect of mycorrhizal fungi on the accumulation of microelements in the plants was observed. Studies by Caris et al. [72] confirmed the fungal effect on iron uptake. An increase in the absorption of the micronutrients manganese (59%), copper (98%), and zinc (87%) was also observed by Castillo et al. [3], who conducted studies on *Capsicum* spp. inoculated with AM fungi. Franco et al. [66] reported increased levels of nitrogen, phosphorus, iron, and zinc in shoots and improved fruit quality. According to those authors, the effect of mycorrhizal inoculation on fruit quality may be closely related to a better nutritional status of plants. According to Majkowska-Gadomska et al. [73], fungi of the *Glomus genera* increased the iron and manganese content of tomato fruit, compared with a control treatment (without fungal strains).

In the present studies, mycorrhization resulted in significant changes in the total sugar content of pepper fruits. The highest content of total sugars was found after mycorrhizal fungi were applied during the planting of the pepper into pots, and the lowest was found as a result of seedling inoculation. Hart et al. [74] found no change in total sugars in tomato fruit due to mycorrhization, but they found a decrease in fructose content and acidity. The authors indicated that AMF typically increased the photosynthetic capacity of host

plants, resulting in more photosynthetic products. However, Li et al. [75] reported that colonization of the root system by AMF might result in carbon outflow from the plant, reducing the amount of sugars in the fruit.

In the present research, the content of polyphenols in the fruits collected from mycorrhized plants and from control plants, grown without mycorrhizal inoculation, did not differ significantly. Castellanos-Morales et al. [76] and Lingua et al. [77] reported that AMF inoculation increased the content of phenols and the oxidative stress resistance of strawberry, and Abdel Latef and Chaoxing [78] observed the same in tomato fruits. Arbuscular mycorrhizal fungi (AMF) may interact with the host plant metabolism, inducing the accumulation of health-promoting phytochemicals and antioxidant molecules [79].

5. Conclusions

Inoculation of the root zone ensured high pepper yields of good quality with significantly reduced top dressing doses. The most beneficial effects were observed after early mycorrhization of the plants, i.e., when inoculate was applied during seedling production, at the time of transferring seedlings from germination trays into pots, when the plants had fully developed cotyledons (BBCH 10 100). The early introduction of mycorrhizal fungi provided adequate time for their colonization of the root system and for the development of the symbiosis between the fungi and pepper roots. On the plots with fungi, lower mineral fertilizer top dressing at 50% and 25% of the basic dose did not cause a statistically significant decrease in pepper yield or a deterioration of the biometric characteristics of the plants and fruits. Despite different amounts of phosphorus supplied with the top dressing, mycorrhiza contributed to similar levels of its accumulation in sweet pepper; on plots with inoculated seedlings, the amount of phosphorus accumulated by plants treated with a full dose of top dressing or with doses reduced to 50% and 25% did not differ significantly. On plots with mycorrhizal fungi applied during the production of seedlings (BBCH 10 100), a reduction in the top dressing dose by 50% resulted in a statistically significant increase in the amount of potassium, calcium, and magnesium accumulated in pepper fruits. In plots with mycorrhiza applied during the transferring of seedlings to pots (BBCH 51 501–52 502), the top dressing dose of 50% resulted in a significant increase in fruit sodium content. Mycorrhizal inoculation, regardless of the application time, also contributed to a higher amount of iron, manganese, copper, and zinc compared to the fruits of non-mycorrhized plants.

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