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Arbuscular mycorrhizal fungi influence the horticultural performance of strawberry cultivars

Fungos micorrízicos arbusculares influenciam o desempenho hortícola de cultivares de morangueiro

Hongos micorrízicos arbusculares influyen en el rendimiento hortícola de los cultivares de fresa

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Abstract
The inoculation of strawberry cultivars with arbuscular mycorrhizal fungi (AMF) is a profitable and viable biotechnological tool, with potential to improve the horticultural performance of plants. However, this biotechnology is lacking and unknown to producers. The aim of the research was to investigate whether strawberry cultivars in the absence and presence of inoculation with AMF differ in their horticultural performance. The treatments, delineated in a bifactorial scheme, were four strawberry cultivars in the absence and presence of two AMF-based inoculants. The experiment was designed in randomized blocks, with three replications. The root system of 'Albion' cultivar showed the highest mycorrhizal colonization. *Claroideoglomus etunicatum* showed greater capacity to infect plant roots.

'Portola' was the most productive cultivar and 'Albion' and 'Aromas' produced strawberries with the highest levels of total anthocyanins. It is concluded that the use of mycorrhizal biotechnology enhances the levels of total flavonoids in fruits of the 'Albion' cultivar inoculated with the fungal species *C. etunicatum*. The root system of 'Albion' cultivar has greater mycorrhizal colonization. The fungal species *C. etunicatum* is more effective in colonizing the roots of the plant host. It is suggested to use the 'Portola' cultivar to obtain higher fruit yields and the 'Albion' and 'Aromas' cultivars for producers who aim to obtain strawberries with higher levels of total anthocyanins. 'Aromas' is recommended for those seeking a dual purpose (production and quality).
Keywords: *Fragaria* X *ananassa* Duch.; Arbuscular mycorrhizal; Production; Quality.

Resumo

A inoculação de cultivares de morangueiro com fungos micorrízicos arbusculares (FMA) é uma ferramenta biotecnológica rentável e viável, com potencial para melhorar o desempenho hortícola das plantas. No entanto, essa biotecnologia é carente e desconhecida aos produtores. O objetivo da pesquisa foi investigar se cultivares de morangueiro na ausência e presença de inoculação com FMA diferem quanto ao seu desempenho hortícola. Os tratamentos, delineados em esquema bifatorial, foram quatro cultivares de morangueiro na ausência e presença de dois inoculantes à base de FMA. O experimento foi delineado em blocos casualizados, com três repetições. O sistema radicial da cultivar Albion apresentou a maior colonização micorrízica. *Claroideoglomus etunicatum* apresentou maior capacidade de infectar as raízes das plantas. Portola foi a cultivar mais produtiva e Albion e Aromas produziram morangos com os maiores teores de antocianinas totais. Conclui-se o uso da biotecnologia micorrízica potencializa os teores de flavonoides totais em frutos da cultivar Albion inoculada com a espécie fúngica *C. etunicatum*. O sistema radicial da cultivar Albion tem maior colonização micorrízica. A espécie fúngica *C. etunicatum* é mais eficaz em colonizar as raízes do hospedeiro vegetal. Sugere-se o uso da cultivar Portola para obter maior rendimento de frutos e as cultivares Albion e Aromas para produtores que visam obter morangos com maiores teores de antocianinas totais. A cultivar Aromas é indicada aqueles que buscam o duplo propósito (produção e qualidade).
Palavras-chave: *Fragaria* X *ananassa* Duch.; Micorriza arbuscular; Produção; Qualidade.

Resumen

La inoculación de cultivares de fresa con hongos micorrízicos arbusculares (HMA) es una herramienta biotecnológica rentable y viable, con potencial para mejorar el rendimiento hortícola de las plantas. Sin embargo, esta biotecnología es deficiente y desconocida para los productores. El objetivo de la investigación fue investigar si los cultivares de fresa en ausencia y presencia de inoculación con HMA difieren en su rendimiento hortícola. Los tratamientos, delineados en un esquema bifactorial, fueron cuatro cultivares de fresa en ausencia y presencia de dos inoculantes basados en HMA. El experimento se diseñó en bloques al azar, con tres repeticiones. El sistema de raíces del cultivar Albion mostró la mayor colonización de micorrizas. Claroideoglomus etunicatum mostró mayor capacidad para infectar raíces de plantas. Portola fue el cultivar más productivo y Albion y Aromas produjeron fresas con los niveles más altos de antocianinas totales. Se concluye que el uso de biotecnología micorrízica mejora los niveles de flavonoides totales en frutos del cultivar Albion inoculados con la especie fúngica C. etunicatum. El sistema de raíces del cultivar Albion tiene una mayor colonización de micorrizas. La especie fúngica C. etunicatum es más eficaz para colonizar las raíces de la planta huésped. Se sugiere utilizar el cultivar Portola para obtener mayores rendimientos de frutos y los cultivares Albion y Aromas para productores que buscan obtener fresas con mayores niveles de antocianinas totales. Cultivar Aromas se recomienda para aquellos que buscan un doble propósito (producción y calidad).
Palabras clave: *Fragaria* X *ananassa* Duch.; Micorriza arbuscular; Producción; Calidad.

1. Introduction

The strawberry (*Fragaria* X *ananassa* Duch.) production in Brazil (165,000 tons) (Antunes; Bonow; Reisser Júnior, 2020) is still concentrated in the conventional cultivation system (on ground, in open sky), with low productivity (36.6 $t.ha^{-1}$) when compared to countries considered the largest producers, such as the United States of America (67.9 $t.ha^{-1}$) and Spain (52.8 $t.ha^{-1}$) (Chiomento, et al., 2020). These data show the Brazilian challenge in introducing new technologies to reduce the productivity gap between the more developed countries. One of the initiatives observed in southern Brazil is the migration of producers from traditional soil cultivation to substrate cultivation, in a protected environment, and the use of cultivars classified as having neutral days regarding flowering.

Due to the low availability of nutrients in the substrates, the use of this input as a plant growth medium requires many chemical fertilizers (Andrade, et al., 2017). Furthermore, most producers who cultivate in substrate establish open systems,

where the drained and surplus nutrient solution is released into the environment, which can cause the contamination of the agroecosystem. An alternative to minimize these inconveniences is to use sustainable tools in strawberry cultivation, such as arbuscular mycorrhizal fungi (AMF). However, mycorrhizal biotechnology is lacking and unknown to most producers. Thus, so that strawberry producers can introduce new technologies during cultivation and at the same time enhance sustainable agriculture, the following question arises: how is the horticultural performance of strawberry cultivars in the absence and presence of inoculation with AMF? The hypothesis for this question is that strawberry cultivars inoculated with AMF produce more fruits and with higher quality.

In strawberry cultivation, AMF, microorganisms that establish symbiotic associations with 80% of the terrestrial flora (Berruti, et al., 2016), benefit the morphology of the plant's root system (Chiomento, et al., 2019a) and improve the phytochemical quality of fruits (Chiomento, et al., 2019a; Parada, et al., 2019). Although the combined benefits of AMF and strawberry cultivars are possibly stronger than the unique effect of each, most studies have focused on investigating each of these tools in isolation. Thus, little is known about the interactive effect of AMF and cultivars during the strawberry production cycle.

Here we investigate whether strawberry cultivars in the absence and presence of inoculation with AMF differ in their horticultural performance. This study provides an overview of mycorrhizal colonization, yield and phytochemical quality of fruits of strawberry cultivars subjected to mycorrhizal biotechnology.

2. Material and Methods

2.1 Plant Material

The research was developed at the Horticulture Sector of the University of Passo Fundo (28º 15’ 46” S, 52º 24’ 24” W), Passo Fundo, Rio Grande do Sul (RS), Brazil, in agricultural greenhouses, from June (winter) 2018 to March (Autumn) 2020.

Strawberry matrices of the ‘Albion’, ‘Aromas’, ‘Monterey’ and ‘Portola’ cultivars, classified as neutral days regarding to flowering, from the Llahuén/Chilean Patagonia nursery (33º 50’ 15.41” S, 70º 40’ 03.06” W), were transplanted in June 2018 in containers filled with commercial substrate Horta 2®, which were kept on benches 1.2 m high, for the purpose of producing stolons. Horta 2® substrate consists of pine bark, vermiculite, acidity correctives and fertilizers (nitrogen, phosphorus and potassium) in quantities not provided by the manufacturer. The cultivation of strawberry plants was developed in a 430 m^2 galvanized steel agricultural greenhouse.

After nine months, in March 2019, stolons were removed from the arrays and transferred to polystyrene trays filled with sterilized S10B® substrate to obtain clod rooted daughter plants, which constituted the plant material for the research. The daughter plants were acclimatized for eight weeks in a greenhouse of 90 m^2. The irrigation used in the acclimatization was with sprinklers, in the mechanized system, with a flow of 1.8 $L.min^{-1}$ per unit. The irrigation regime consisted of activating the sprinklers seven times a day, with a total watering of 14 min. The water blade supplied to daughter plants was 7.8 $mm.day^{-1}$.

2.2 Experimental Design

The treatments, delineated in a bifactorial scheme, were four strawberry cultivars (‘Albion’, ‘Aromas’, ‘Monterey’ and ‘Portola’) in the absence (control) and presence of two AMF-based inoculants [*Claroideoglomus etunicatum* (WN Becker & Gerd.) C. Walker & Gerd. A. Schüßler and the mycorrhizal community]. The experiment was designed in randomized blocks, with three replications of a single plant.

The isolate *C. etunicatum* SCT101A was from the International Culture Collection of Glomeromycota (CICG). On the

other hand, the AMF community used came from an agricultural crop soil trap collected in a strawberry crop reference site in the municipality of São José do Hortêncio (29º 29' 33" S, 51º 12' 24" W), RS (Chiomento, et al., 2019b), composed of ten fungal species, according to the Glomeromycota classification by Redecker, et al. (2013): *Acaulospora foveata* Trappe & Janos, *Claroideoglomus* aff. *luteum*, *C. claroideum* (N.C. Schenck & G.S. Sm.) C. Walker & A. Schüßler, *C. etunicatum* (W.N. Becker & Gerd.) C. Walker & A. Schüßler, *Funneliformis* aff. *geosporum*, *Funneliformis* aff. *mosseae*, *F. mosseae* (T.H. Nicolson & Gerd.) C. Walker & A. Schüßler, *Glomus* aff. *versiforme*, *Glomus* sp. (*caesaris* like) and *Glomus* sp2.

2.3 Cultivation Techniques

In May 2019, after eight weeks of acclimatization, the clod rooted daughter plants obtained were transplanted into 5 L polyethylene pots filled with sterilized S10B® substrate. For the treatments inoculated with AMF, 10 g of inoculant were added in the planting hole of the daughter plants, at the time of transplantation. A 500 g sample of the S10B® substrate was analyzed to obtain its physical and chemical attributes (Table 1).

Table 1. Physical and chemical characterization of the substrate S10B®. Passo Fundo, RS, 2019.

Physical properties[1]						
Substrate	D	TP	AS	RAW	BW	RW
	($kg.m^{-3}$)	($m^3.m^{-3}$)				
S10B®	241	0.861	0.459	0.155	0.024	0.223

Chemical properties[2]							
Substrate	N	P	K	OC	pH	EC	CEC
	% ($m.m^{-1}$)					$mS.cm^{-1}$	$mmol_c.kg^{-1}$
S10B®	1.01	0.36	0.14	21.28	4.6	1.12	473.34

[1] D: density; TP = total porosity; AS: aeration space; RAW: readily available water; BW: buffer water; RW: remaining water.
[2] N: nitrogen; P: phosphorus; K: potassium; OC: organic carbon; pH: potential of hydrogen; EC: electric conductivity; CEC: cation exchange capacity.
Source: authors' data (2019).

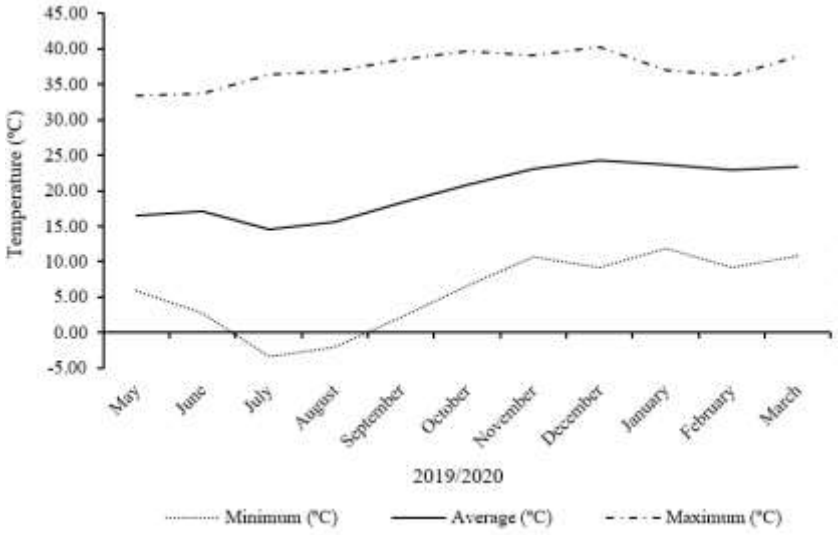
The pots were kept on benches, 1.2 m from the soil surface, in a greenhouse of 430 m^2, covered with a low-density polyethylene film, with an anti-ultraviolet additive and with a thickness of 150 microns, installed in the northwest-southeast direction. The irrigation used in the experiment was located, using drip rods, in the mechanized system, with a flow rate of 2.28 $L.h^{-1}$ per unit. The irrigation regime consisted of activating the dripping rods six times a day with a total watering of 12 min. The nutrient solutions supplied to the plants every two weeks via fertigation were made according to Furlani and Fernandes Júnior (2004), but with a 50% reduction in the supply of phosphorus (Table 2). A mini meteorological station was used to monitor air temperature (minimum, average and maximum) inside the greenhouse (Figure 1).

Table 2. Compositions of nutritional solutions with a 50% reduction in the supply of phosphorus to strawberry soilless cultivation. Passo Fundo, RS, 2019.

Fertilizers	Nutritional solutions ($g.L^{-1}$ H_2O)[1]		
	A	B	C
Calcium nitrate	160	0	0
Potassium nitrate	0	114	125
Monoammonium phosphate	0	15	0
Monopotassium phosphate	0	18	36
Magnesium sulfate	0	120	120
Boric acid	0.6	0	0
Copper sulphate	0.06	0	0
Manganese sulphate	0.4	0	0
Zinc sulfate	0.2	0	0
Sodium molybdate	0.06	0	0
Iron chelate (6% Fe)	12	0	0

[1] Solutions A and B: given in the vegetative stage; solutions A and C: given in the reproductive stage.
Source: Furlani e Fernandes Júnior (2004).

Figure 1. Minimum, average and maximum monthly temperatures inside the greenhouse during the experiment. The general average temperature recorded during the experiment was 20.02ºC.



Source: authors' data (2019/2020).

2.4 Mycorrhizal Colonization

To verify the infective capacity of the AMF, at the end of the experiment (March 2020) portions of mycorrhizal plant roots were prepared according to Phillips and Hayman (1970) and their percentage of mycorrhizal colonization (MC, %) was determined according to Trouvelot, Kough and Gianinazzi-Pearson (1986), by the equation:

$$MC\ (\%) = \frac{\text{total number of fragments with mycorrhized root}}{\text{total number of fragments}} \times 100 \quad (1)$$

2.5 Fruit Production

From fruiting in September (spring) 2019, the total number of fruits per plant (TNF, number per plant) and the total production of fruits per plant (TP, grams per plant) were evaluated, harvested when they presented from ¾ to fully ripe. The

fruits were weighed in an electronic digital scale. In addition, the average fresh fruit mass (AFFM, grams) was determined by dividing TP and TNF.

2.6 Strawberry Phytochemical Quality

At the peak of fruit maturation [November (spring) 2019], the phytochemical quality of the fruit was evaluated. Thus, the harvested strawberries (100 grams) were submitted to the phytochemical extraction procedure, carried out according to Revilla, Ryan and Martin-Ortega (1998). Afterwards, the levels of total anthocyanins (TA), antioxidant activity (AA), total flavonoids (TF) and total polyphenols (PL) were quantified. The TA content was determined by the differential pH method (Giusti; Wrolstad, 2001; Lee; Durst; Wrolstad, 2005) and the results were expressed in milligrams of pelargonidin-3-*O*-glycoside equivalent per 100 grams of fresh fruit (mg PE/100 g FF^{-1}). The determination of AA was made by the power of iron reducing activity (Zhu, et al., 2002) and the results were expressed in milligrams of gallic acid equivalent per 100 grams of fresh fruit (mg GAE/100 g FF^{-1}). The TF content, performed according to Miliauskas, Venskutonis and Van Beek (2004), was expressed in milligrams of rutin per 100 grams of fresh fruit (mg rutin/100 g FF^{-1}). PL content was determined by the Folin-Ciocalteu method (Singleton; Orthofer; Lamuela-Raventos, 1999) and results were expressed in milligrams of gallic acid equivalent per 100 grams of fresh fruit (mg GAE/100 g FF^{-1}).

2.7 Statistical Analysis

The data obtained were subjected to analysis of variance and, when there was significance, the means of the treatments were compared using the Tukey test, at 5% probability of error, using the Costat® program.

3. Results

3.1 Mycorrhizal Colonization

There was an effect of mycorrhizal cultivars and inoculants, in isolation, on mycorrhizal colonization of the root system of strawberry plants (Table 3).

Table 3. Summary of analysis of variance for mycorrhizal colonization of roots of strawberry cultivars in the absence and presence of inoculation with AMF. Passo Fundo, RS, 2020.

Causes of variation	DF[1]	Mean square
		Mycorrhizal colonization (%)
Blocks	2	86.11^{ns}
Cultivars	3	166.66*
AMF	2	19544.44**
Cultivars x AMF	6	55.55^{ns}
Residue	22	52.77
Total	35	
Mean		46.11
CV (%)[2]		15.75

[1] DF: degrees of freedom.
[2] CV: coefficient of variation.
* significant at the 5% probability level ($0.01 \leq p < 0.05$).
** significant at the 1% probability level ($p < 0.01$).
^{ns} not significant ($p \geq 0.05$).
Source: authors' data (2020).

The AMF structures observed in the roots were hyphae, vesicles and arbuscules. The root system of the 'Albion' cultivar showed mycorrhizal colonization 20% higher than that of the 'Portola' cultivar, but without statistically differing from the 'Aromas' and 'Monterey' cultivars (Table 4). Among the fungal treatments evaluated, it was observed that *C. etunicatum* had a greater capacity to infect plant roots in relation to the mycorrhizal community (Table 4).

Table 4. Mycorrhizal colonization of roots of strawberry cultivars in the absence and presence of inoculation with AMF. Passo Fundo, RS, 2020.

Cultivars	Mycorrhizal colonization (%)
'Albion'	50.00 ± 19.69 a
'Aromas'	47.77 ± 16.32 ab
'Monterey'	46.66 ± 15.71 ab
'Portola'	40.00 ± 10.41 b
AMF	
Control	00.00 ± 00.00 c
Community	63.33 ± 17.56 b
C. etunicatum	75.00 ± 19.48 a
Mean	46.11
CV[1]	15.75

Data presented as mean ± standard deviation. Means followed by the same letter in the column do not differ significantly by Tukey's test ($p \leq 0.05$).
[1] CV: coefficient of variation.
Source: authors' data (2020).

3.2 Fruit Production

In relation to fruit production, there was a significant effect only of cultivars in relation to the attributes TNF, TP and AFFM (Table 5).

Table 5. Summary of analysis of variance for fruit yield of strawberry cultivars in the absence and presence of AMF inoculation. Passo Fundo, RS, 2020.

Causes of variation	DF[1]	Mean square		
		TNF (number per plant)[2]	TP (grams per plant)	AFFM (grams)
Blocks	2	1416.69*	163096.89*	0.47^{ns}
Cultivars	3	1706.99**	203387.91**	8.40*
AMF	2	161.69^{ns}	127142.27^{ns}	8.76^{ns}
Cultivars x AMF	6	304.10^{ns}	26469.45^{ns}	1.69^{ns}
Residue	22	263.66	31041.77	2.57
Total	35			
Mean		72.97	945.40	13.15
CV (%)[3]		12.25	18.63	12.20

[1] DF: degrees of freedom.
[2] TNF: total number of fruits; TP: total production; AFFM: average fresh fruit mass.
[3] CV: coefficient of variation.
* significant at the 5% probability level ($0.01 \leq p < 0.05$).
** significant at the 1% probability level ($p < 0.01$).
^{ns} not significant ($p \geq 0.05$).
Source: authors' data (2020).

Strawberry cultivars were grouped into three extracts for TNF (Table 6). 'Aromas' and 'Portola' stood out for the largest amount of fruit produced, followed by the cultivar 'Monterey' and then, as the last extract, the 'Albion' cultivar (Table 6). The highest fruit production was obtained by 'Aromas', 'Monterey' and 'Portola' cultivars, which on average produced

28% more than 'Albion' cultivar (Table 6). 'Albion', 'Monterey' and 'Portola' cultivars had the highest AFFM, differing only from 'Aromas' cultivar, which produced strawberries with the lowest AFFM (Table 6).

Table 6. Fruit production of strawberry cultivars. Passo Fundo, RS, 2020.

Cultivars	TNF (number per plant)[1]	TP (grams per plant)	AFFM (grams)
'Albion'	53.33 ± 15.44 b	729.44 ± 142.00 b	13.57 ± 1.50 a
'Aromas'	84.55 ± 28.10 a	976.68 ± 189.87 a	11.71 ± 1.11 b
'Monterey'	74.11 ± 11.34 ab	998.17 ± 159.84 a	13.64 ± 2.20 a
'Portola'	79.88 ± 13.82 a	1077.2 ± 100.16 a	13.69 ± 1.53 a
Mean	72.97	945.40	13.15
CV (%)[2]	12.25	18.63	12.20

Data presented as mean ± standard deviation. Means followed by the same letter in the column do not differ significantly by Tukey's test ($p \leq 0.05$).
[1] TNF: total number of fruits; TP: total production; AFFM: average fresh fruit mass.
[2] CV: coefficient of variation.
Source: authors' data (2020).

3.3 Strawberry Phytochemical Quality

As for the contents of phytochemicals in strawberries, an isolated effect of the cultivars was observed for the content of TA and an interactive effect between cultivars and inoculants regarding the content of TF (Table 7).

Table 7. Summary of the analysis of variance for phytochemical contents in fruits of strawberry cultivars in the absence and presence of inoculation with AMF. Passo Fundo, RS, 2020.

Causes of variation	DF[1]	Mean square			
		TA (mg EP/100 g FF^{-1})[2]	AA (mg EAG/100 g FF^{-1})	TF (mg rutin/100 g FF^{-1})	PL (mg EAG/100 g FF^{-1})
Blocks	2	0.46^{ns}	43824.85^{ns}	16.24^{ns}	19759.51^{ns}
Cultivars	3	10.66**	55251.91^{ns}	1434.04**	66107.92^{ns}
AMF	2	0.64^{ns}	15302.04^{ns}	493.98^{ns}	42375.74^{ns}
Cultivars x AMF	6	1.11^{ns}	16110.21^{ns}	565.21*	61611.09^{ns}
Residue	22	0.65	23055.51	150.45	41591.64
Total	35				
Mean		2.11	394.57	43.58	983.03
CV (%)[3]		18.29	18.48	18.14	10.74

[1] DF: degrees of freedom
[2] TA: total anthocyanins; AA: antioxidant activity; TF: total flavonoids; PL: total polyphenols.
[3] CV: coefficient of variation.
* significant at the 5% probability level ($0.01 \leq p < 0.05$).
** significant at the 1% probability level ($p < 0.01$).
^{ns} not significant ($p \geq 0.05$).
Source: authors' data (2020).

Fruits of the 'Albion' cultivar produced in substrate containing the fungal species *C. etunicatum* had higher TF contents (Table 8).

Table 8. Association of strawberry and AMF cultivars in terms of total flavonoid content in fruits. Passo Fundo, RS, 2020.

Cultivars	Total flavonoids (mg rutin/100 g FF^{-1})		
	AMF		
	Control	Community	*C. etunicatum*
'Albion'	30.06 ± 06.82 Bb	57.01 ± 08.38 ABa	67.56 ± 06.84 Aa
'Aromas'	61.41 ± 10.12 Aa	55.25 ± 12.06 Aa	54.67 ± 06.59 Aab
'Monterey'	42.65 ± 10.99 Aab	28.00 ± 11.35 Ab	29.76 ± 08.38 Ab
'Portola'	19.80 ± 04.84 Ab	25.66 ± 10.59 Ab	51.15 ± 10.04 Aab
Mean		43.58	
CV (%)[1]		18.14	

Data presented as mean ± standard deviation. Means followed by the same uppercase letter in the row and lowercase letter in the column do not differ by Tukey's test ($p \leq 0.05$).
[1] CV: coefficient of variation.
Source: authors' data (2020).

'Albion' and 'Aromas' cultivars produced fruits with the highest levels of TA, differing statistically from 'Monterey' and 'Portola' cultivars, which produced fruits with the lowest levels of this biomolecule (Table 9).

Table 9. Total anthocyanin contents of fruits of strawberry cultivars. Passo Fundo, RS, 2020.

Cultivars	Total anthocyanins (mg EP/100 g FF^{-1})
'Albion'	2.92 ± 0.69 a
'Aromas'	3.17 ± 0.38 a
'Monterey'	1.27 ± 0.55 b
'Portola'	1.07 ± 0.55 b
Mean	2.11
CV[1]	18.29

Data presented as mean ± standard deviation. Means followed by the same letter in the column do not differ significantly by Tukey's test ($p \leq 0.05$).
[1] CV: coefficient of variation.
Source: authors' data (2020).

4. Discussion

Unlike expected, mycorrhization did not significantly benefit strawberry production (Table 5). However, considering the materials evaluated, the highest fruit production was obtained by the 'Portola' cultivar (Table 6). The literature reports different productive performances of cultivars in relation to the different managements adopted by researchers, such as the environment and cultivation system used. In research carried out in southern Brazil, with cultivars planted in the soil in a protected environment, the yield obtained (grams per plant) was 296, 218, 421 and 327 for the 'Albion', 'Aromas', 'Monterey' and 'Portola' cultivars, respectively (Chiomento, et al. al., 2021a). In our research, the low production of 'Albion' cultivar (Table 6) may be related to the inadaptability of this material to the place of cultivation. This shows that productivity in different agroecosystems varies due to the range of plant responses related to edaphoclimatic (Zanin, et al., 2019) and ecophysiological (Costa, et al., 2021) factors.

In recent decades there has been an increase in interest in the consumption of berry-like fruits, which contain the best sources of bioactive compounds (Skrovankova, et al., 2015), such as strawberries. These bioactive substances reduce oxidative stress and counteract the overproduction of reactive oxygen species, which are related to the occurrence of various diseases (Atmani, et al., 2009). These effects on human health have been related to the antioxidant activity of phenolic compounds, mainly anthocyanins (Olsson, et al., 2006), detected in this study (Table 7). The lower phytochemical performance of 'Portola' cultivar (Table 9) confirms (Ganhão, et al., 2019) and contradicts (Lester, et al., 2012) results of other researches. This

divergence of results from the literature can be explained by the influence of the strawberry harvest period, the edaphoclimatic conditions of cultivation and the production systems adopted (Harakotr, et al., 2014). However, the variability in the phytochemical composition of strawberries obtained in this study cannot be explained by the aforementioned factors, as all cultivars were planted under the same greenhouse conditions. Thus, differences in phytochemical contents are attributed to the genetic factor, that is, to the cultivated genotypes, which was also demonstrated by Gunduz and Ozdemir (2014).

As expected, the benefit of mycorrhization on the phytochemical quality of strawberries produced by the 'Albion' cultivar inoculated with *C. etunicatum* was proven (Table 8). The benefit of AMF on strawberry quality has been reported in other research (Chiomento, et al., 2019a; Chiomento, et al., 2021b). The dynamics of these microorganisms in the secondary metabolism of plants results in enhanced biosynthesis of phytochemicals with beneficial properties to health (Basu; Rabara; Negi, 2018). These higher concentrations of phytochemicals in the fruits (Table 8) can be attributed to the activation of a defense response of the strawberry plant to mycorrhizal colonization (Lingua, et al., 2013), observed in the roots of the analyzed plants (Table 4).

In strawberry crops, mycorrhization can generate different growth responses and fruit production/quality (Chiomento, et al., 2019a; Chiomento, et al., 2021b; Costa, et al., 2020). Therefore, the only studies on AMF surveys in soils cultivated with strawberry (Chiomento, et al., 2019b; Pedersen, et al., 2017) are important to elect fungal species that have an affinity with this horticulture. Thus, our results are unprecedented because we inoculated four strawberry cultivars with a mycorrhizal community from soil adapted to the cultivation of this vegetable. One of the factors influencing the positive effects of arbuscular mycorrhiza is the choice of fungal species (Fortuna, et al., 1992). The use of host-compatible AMF commonly provides more satisfactory results (Koron; Sonjak; Regvar, 2014).

Due to people's preference for the consumption of foods rich in biomolecules, our results confirmed the potential of applying mycorrhizal biotechnology in strawberry plants as a valuable tool to improve the total flavonoid content in fruits produced by the 'Albion' cultivar inoculated with *C. etunicatum*. In addition, our findings contribute for producers to choose cultivars with greater productive potential and better phytochemical quality, when inserted in substrate and in a protected environment. This makes it possible to positively impact producers' income and boost the strawberry production chain. The knowledge of this horticultural variability of the four cultivars studied can be useful for the selection of more productive materials and/or rich in bioactive compounds or even to guide professionals working in strawberry genetic improvement programs, stimulating the development of new cultivars with bigger fruits and with better quality, for example. Finally, these investigations are filling the gap between strawberry cultivars combined with AMF.

5. Conclusion

The combination between cultivars and AMF can be an option for growing strawberry in substrate because this interface benefits the phytochemical quality of fruits. The use of mycorrhizal biotechnology enhances the levels of total flavonoids in fruits of the 'Albion' cultivar inoculated with the fungal species *C. etunicatum*. The root system of the 'Albion' cultivar presents greater mycorrhizal colonization. The fungal species *C. etunicatum* is more effective in colonizing the roots of the plant host. In addition, we suggest to strawberry growers the use of the 'Portola' cultivar to obtain greater production, number and size of fruits and we recommend the 'Albion' and 'Aromas' cultivars for producers aiming to obtain strawberries with higher total anthocyanin contents. 'Aromas' cultivar is recommended for those seeking a dual purpose (production and quality). Future research should focus on: (1) understanding the interaction among other AMF species and strawberry cultivars; (2) evaluate the efficiency of mycorrhization under conditions of multiple stressors (water and nutritional deficits, for example).

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