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Effects of AMF on nutrient and stoichiometric characteristics in different organs of sunflower

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Abstract

In order to explore the effects of arbuscular mycorrhizal fungi (AMF) on growth and nutrient absorption for ornamental sunflowers, explain the related physiological mechanism, four species of AMF *Acaulospora scrobiculata* (AS), *Diversispora spurca* (DS), *Funneliformis mosseae* (FM) and *Diversispora versiformis* (DV) were selected, and inoculated into potted ornamental sunflower seedlings under greenhouse condition. Effects of AMF on growth, nutrient absorption and ion balance of ornamental sunflower were analyzed. Results showed that four different AMF could infect sunflower roots. In which, DS inoculation has the highest mycorrhizal colonization; whereas, the mycelial length of DV treatment in rhizosphere soil was significantly higher than the other three AMF treatments. Four kinds of AMF markedly decreased the fresh weight in roots and leaves, but significantly increase the fresh weight in flower discs. Furthermore, the four different AMF increased the nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) contents in roots, leaves and flower discs of sunflower in varying degrees, meanwhile reduced the N:P and N:K in root and the flower discs. In addition, the four different AMF significantly reduced the sodium ion (Na^+) concentration but significantly increased K^+/Na^+, Ca^{2+}/Na^+ and P/Na^+ in flower discs. The correlation analysis showed that there was a significant positive correlation between the mycorrhizal infection rate and the content of P or K in roots, or P, K, Ca in leaves, or N, K in flower discs in various organs of sunflower. In short, AMF could promote ornamental sunflower growth by ameliorating nutrient absorption and transport, adjusting the distribution of mineral elements in organs and the balance between ions, to enhance adaptability and ecological benefits.

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Introduction

Mineral elements are essential for plant growth, while different plants often show an imbalance for nutrients due to their different requirements and utilization rates of each nutrient. For example, K^+/Na^+ imbalance can disrupt various metabolic pathways (Zhou, 2019), and Ca^{2+}/Na^+ imbalance can affect photosynthesis and water transport among plants, which in return can affect plant growth (Cramer, 2002). Therefore, understanding and maintaining the balance of each nutrient in plant is a primary requirement for the development of robust plants.

Arbuscular mycorrhizal fungi (AMF) are a group of beneficial microorganisms in soil, formed after infesting the roots of terrestrial plants. This reciprocal symbiotic structure serves as a transport carrier between soil and plants, which has a positive effect in enhancing water and nutrient uptake and plant growth by the root system of the host plant (Cheng et al., 2020). Moreover, under biotic and abiotic stresses, the widespread external hyphae can expand the uptake area for host plant, and promote their uptake and transport of mineral elements, also alleviate the damage caused by various stresses to plants (Qu et al., 2019). For example, results by Zhang et al. (2012) on loquat seedlings showed that three different AMF significantly enhanced their uptake of nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), zinc (Zn), and cuprum (Cu), with more pronounced effects under water stress condition. In addition, AMF selectively absorbed K and Ca, thus regulating the balance of ions in the host plant and alleviating the toxic effects of adverse environmental conditions, especially Na^+ on plants under salt stress (Shen et al., 2004; Hammer et al., 2011). However, most of the recent studies on plant ecological stoichiometry only focused on ecological effects at different ages and altitudes, and there are few studies on the ability of AMF to improve host plant stoichiometric characteristics.

Sunflower (*Helianthus annuus* L.) is widely used in landscaping and people's lives because of its high ornamental value as a plant of the family Asteraceae (*Compositae*), its high economic value, as well as its less stringent soil requirements and salinity tolerance (Fu, 2013). Previous studies on the stoichiometric characteristics of AMF on ornamental sunflower have been less involved. In this study, the nutrient content of different organs and their ecological chemometric characteristics by inoculating ornamental sunflower with different AMF were determined to reveal the distribution of nutrients among ornamental sunflower roots, leaves and flower discs, and the regulatory mechanism of AMF on ion balance in sunflower plants were analyzed, which can provide a theoretical basis for future applications of sunflower in gardens and enrich the ecology of ornamental plants. It can also enrich the ecology of ornamental plants.

Materials and methods

Experimental materials

Ornamental sunflower (*Helianthus annuus*) seeds were soaked in cold water for 1 hour and spotted in cavity trays with autoclaved seedling substrate (120℃, 0.1 MPa, 1 hour), and then placed in a light incubator with a diurnal temperature difference of 25 ℃/12 ℃ and relative humidity of 70% for germination. Strains used in this experiment were *Acaulospora scrobiculata* (AS), *Diversispora spurca* (DS), *Diversispora versiformis* (DV) and *Funneliformis mosseae* (FM). They were supplied by Bank of Glomeromycota in China (BGC) and propagated for16 weeks with white clover.

One two-leaf-old sunflower seedlings in the uniform size were selected and transplanted into a plastic pot (15 cm up diameter ×10cm bottom diameter×13cm height) pre-filled with 1.2 kg autoclaved (120 ℃, 0.1 MPa, 2 hour) substrate of soil and grass charcoal (1:1, v: v), one sunflower seedling per pot. After transplanting, the pots were placed in a plastic greenhouse under a diurnal temperature of 30 ℃/18 ℃ (day/night), a photosynthetic photon flux density of 338~982 $\mu mol \cdot m^{-2} \cdot s^{-1}$, and an air relative humidity of 70%.

Experimental design

The experiment was arranged in a single-factor design. Each of the five treatments (AS, DS, DV, FM, Non-AMF) had nine replicates, with a total of 45 pots. All treatments were in a completely randomized arrangement. 85 g of inoculum (approximately 1500 spores) per pot were used in inoculation treatments by the 'stratified inoculation' method. The same autoclaved (120 ℃, 0.1 MPa, 1 hour) strain was used in the Non-AMF treatment as control.

Experimental determination method

After 12 weeks of AMF inoculation, plants were harvested at peak flowering. The sunflower seedlings were removed intact from each pot and weighed separately for the root, leaf and flower disc. Subsequently, 1-2 cm non-apical root segments of each treatment were randomly selected and stained with trypan blue to observe mycorrhizal development under a microscope and record the mycorrhizal colonization (Phillips and Hayman, 1970). About 300 g of rhizosphere soils were collected while the plants were harvested. Stained and the length of soil hyphae length was determined as describe by Bethlenfalvay et al. (1987). Roots, leaves and flower discs of ornamental sunflowers were blanched under 105 ℃ for 30 min, then dried at 70 ℃ to constant weight, subsequently

ground into powder and passed through a 1mm sieve, and the mineral element content of each organ was determined using the method of Shao et al. (2018).

Statistical analysis

The ANOVA procedure of SAS (8.1) software was used to test for differences between treatments, and multiple comparison analysis was performed using Duncan's new complex polar difference method (P<0.05).

Results

Mycorrhizal development

Four different AMF were infested sunflower roots and establish a good symbiosis (Fig. 1), and their infestation ability was DS>AS>DV>FM, and they differed significantly among strains (Table 1). The entry points of AS and DS treatments were significantly higher than those of FM and DV treatments, but there was no significant difference among them. In addition, the length of soil hyphae in rhizosphere soil was highest in DV treatment, reaching 20.24 cm/g (Fig. 1A, Table 1).

Plant growth

Compared to the Non-AMF treatment, inoculation with AMF reduced root and leaf fresh weight of ornamental sunflower plants in varying degrees, but significantly increased flower disc fresh weight by 7.85%, 10.16%, 23.99% and 31.01%, respectively (Table 2). Only DS treatment significantly increased the fresh weight of the stem by 9.23% (Table 2).

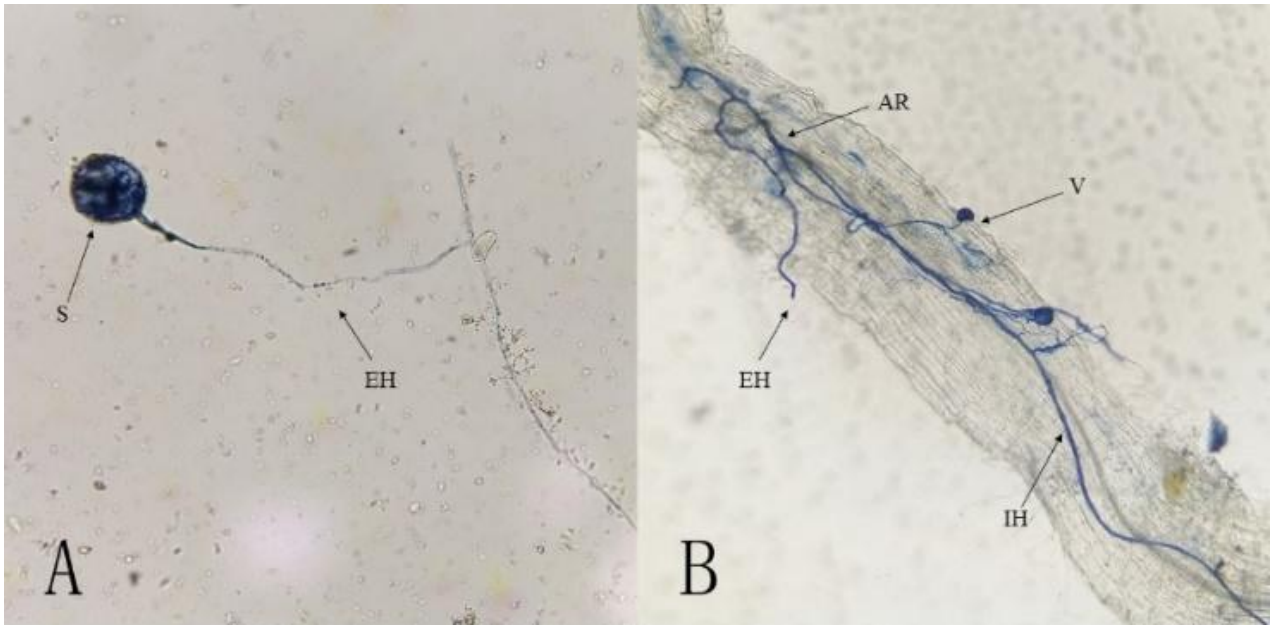

Fig. 1: Status of rhizosphere soil hyphae growth (A: ×400) root AMF colonization (B: ×100) in sunflower.
S: Spore; EH: External hyphae; AR: Arbuscule; V: Vesicle; IH: Internal hyphae.

Table 1. Effects of different AM fungi on mycorrhizal development of sunflower.

Treatments	AMF colonization (%)	Entry points (#/cm)	Soil hyphae length (cm/g)
Non-AMF	0±0e	0±0c	0±0e
AS	34.33±2.15b	2.12±0.17a	12.15±0.52d
DS	48.67±3.69a	2.21±0.19a	13.57±0.51c
FM	18.65±1.57d	1.14±0.11b	15.94±1.06b
DV	26.58±2.81c	1.31±0.15b	20.24±1.14a

Note: Values followed by different letters in a column are significantly different among treatments at $P < 0.05$ level.

Table 2. Effects of different AM fungi on the biomass of sunflower organizations.

Treatments	Root (g)	Stem (g)	Leaf (g)	Flower disc (g)
Non-AMF	46.15±2.05a	38.45±2.60ab	36.32±2.37a	35.05±3.27d
AS	36.38±2.75bc	37.65±2.24b	24.60±0.92d	43.46±2.56b
DS	28.19±1.37d	42.00±2.53a	32.74±0.06b	45.92±2.16a
FM	39.71±1.82b	36.00±2.00c	27.07±2.67c	37.80±3.67c
DV	34.63±2.52c	36.93±0.89bc	24.73±1.80d	38.61±0.65c

Note: Values followed by different letters in a column are significantly different among treatments at $P < 0.05$ level.

Mineral nutrients concentration

Effect of AMF on the mineral element content in various organs of sunflower showed different effects (Table 3). Overall, among the four different AMF treatments, only the DS treatment showed an increasing effect on the mineral element concentrations in different sunflower organs. Compared with Non-AMF treatment, DS significantly increased the N, P, K, Ca, and Mg contents by 10.94%, 45.37%, 40.32%, 15.51%, and 10.98% in root, 5.70%, 24.92%, 10.45%, 25.15%, and 15.81% in leaves, and 6.42%, 18.08%, 27.49%, 12.31%, and 26.49% in flower discs, respectively (Table 3).

Table 3. Effects of different AMF on mineral elements contents in sunflower roots, leaves and flower disc.

Organ	Treatments	N (g/kg)	P (g/kg)	K (g/kg)	Ca (g/kg)	Mg (g/kg)
Root	Non-AMF	6.49±0.56b	2.05±0.18c	24.28±0.45c	7.35±0.95d	1.73±0.06b
	AS	5.05±0.09c	2.56±0.07b	24.71±0.84c	9.95±0.44ab	1.74±0.09b
	DS	7.20±0.17a	2.98±0.07a	34.07±0.93a	8.49±0.66c	1.92±0.05a
	FM	5.62±0.21c	2.93±0.09a	27.62±0.57b	9.29±0.40b	2.09±0.05a
	DV	5.09±0.19c	2.64±0.08b	33.93±0.93a	10.60±0.90a	1.63±0.05c
Leaf	Non-AMF	10.88±0.62c	3.01±0.06c	39.92±0.91d	20.52±1.58c	2.91±0.12c
	AS	13.53±0.98a	3.43±0.07b	42.75±0.82bc	33.25±1.28a	4.19±0.14a
	DS	11.50±0.11b	3.76±0.07a	44.09±0.81b	25.68±0.69b	3.37±0.10b
	FM	12.08±1.43ab	3.02±0.02c	41.82±0.81c	26.76±0.55b	3.49±0.05b
	DV	11.24±0.23bc	3.35±0.08b	47.22±1.00a	30.10±1.25ab	3.08±0.14c
Flower disc	Non-AMF	11.68±0.34b	4.48±0.19c	29.36±0.99d	10.56±0.85c	1.51±0.08e
	AS	12.48±0.31a	4.61±0.29c	30.18±0.45cd	10.00±0.75c	1.99±0.09b
	DS	12.43±0.29a	5.29±0.11b	37.43±1.21a	11.86±0.71b	1.91±0.06c
	FM	11.99±0.29ab	5.70±0.11a	32.68±0.38c	13.59±0.83a	2.26±0.08a
	DV	11.74±0.40b	5.57±0.15ab	34.34±0.66b	10.04±0.47c	1.64±0.08d

Note: Values followed by different letters in a column are significantly different among treatments at $P < 0.05$ level.

Ecological stoichiometric ratio of N: P: K

Compared with Non-AMF, four different AMF significantly reduced root N:P and N:K ratios, with DV decreasing mostly by 39% and 44%, respectively. AS and FM treatments significantly reduced root K:P ratios, while DS and DV had no significant effect on root K:P (Table 4). Compared with Non-AMF, leaf N:K ratio increased by 16.5% under AS treatment and K:P ratio decreased by 6.18% and 13.73% under AS and DS treatments, respectively, while other AMF treatments and other N:P:K stoichiometric ratios in leaves were not significantly different (Table 4). In addition, DS, FM and DV significantly reduced the flower disc N:P and N:K ratios, which were not significantly affected by AS treatment, the flower disc K:P ratio was reduced by 12.79% after inoculation with FM, which was not significantly different in the other treatments (Table 4).

Na^+ uptake

Compared with Non-AMF, FM inoculation significantly increased sunflower root Na^+ concentration and content by 29.44% and 11.33%, respectively. AS, DS and DV treatments had no significant effect on root Na^+ concentration, but DS and DV significantly decreased

root Na^+ content (Table 5). The four different AMF had no significant effect on sunflower leaf Na^+ concentration, but significantly reduced leaf Na^+ content, and there was no significant difference between the four AMF treatments (Table 5). In addition, four AMF significantly reduced sunflower disc Na^+ concentration, FM and DV also significantly reduced disc Na^+ content, while DS significantly increased disc Na^+ content by 14.88% (Table 5).

Ionic balance

Both DS and DV treatments significantly increased the K^+/Na^+, Ca^{2+}/Na^+ and P/Na^+ ratio in different sunflower organs. AS had no significant effect on root K^+/Na^+, leaf K^+/Na^+ and P/Na+ ratio, FM decreased the root K^+/Na^+ ratio and had no significant effect on Ca^{2+}/Na^+ ratio, except for other tissues and their ion equilibrium ratios all showed an increasing trend (Table 6).

Table 4. Effects of different AM fungi on the N: P: K of sunflower roots, leaves and flower disc.

Treatments	Root (g/kg)			Leaf (g/kg)			Flower disc (g/kg)		
	N:P	N:K	K:P	N:P	N:K	K:P	N:P	N:K	K:P
Non-AMF	3.178± 0.130a	0.268± 0.027a	11.94± 1.20ab	3.611± 0.137ab	0.272± 0.012bc	13.26± 0.29b	2.601± 0.036a	0.398± 0.025a	6.57± 0.50ab
AS	1.973± 0.045c	0.204± 0.006b	9.66± 0.55c	3.938± 0.273a	0.317± 0.028a	12.44± 0.26c	2.711± 0.114a	0.413± 0.012a	6.57± 0.48ab
DS	2.413± 0.034b	0.211± 0.07b	11.43± 0.48b	3.056± 0.086b	0.261± 0.004bc	11.72± 0.39d	2.351± 0.061b	0.332± 0.011c	7.08± 0.37a
FM	1.926± 0.079c	0.204± 0.009b	9.42± 0.48c	3.997± 0.492a	0.289± 0.030ab	13.83± 0.31ab	2.103± 0.091b	0.367± 0.006b	5.73± 0.16c
DV	1.918± 0.058c	0.150± 0.007c	12.84± 0.74a	3.362± 0.147ab	0.238± 0.008c	14.12± 0.56a	2.107± 0.040b	0.342± 0.005bc	6.16± 0.18b

Note: Values followed by different letters in a column are significantly different among treatments at $P < 0.05$ level.

Table 5. Effects of different AMF on Na^+ absorption of sunflower.

Treatments	Na^+ Concentration (g/kg)			Na^+ Content (g/pot)		
	Root	Leaf	Flower disc	Root	Leaf	Flower disc
Non-AMF	1.80±0.07bc	0.41±0.02ab	0.48±0.01a	8.31±0.71ab	1.49±0.010a	1.68±0.15b
AS	1.97±0.10b	0.45±0.04a	0.36±0.01c	7.17±0.58b	1.11±0.011b	1.56±0.10b
DS	1.61±0.07c	0.36±0.04b	0.42±0.02b	4.54±0.26d	1.18±0.007b	1.93±0.17a
FM	2.33±0.03a	0.37±0.03b	0.34±0.01c	9.25±0.79a	1.00±0.005b	1.29±0.01c
DV	1.82±0.08bc	0.38±0.01b	0.31±0.02d	6.30±0.41c	0.94±0.007b	1.20±0.11c

Note: Values followed by different letters in a column are significantly different among treatments at $P < 0.05$ level.

Table 6. Effects of different AM fungi on ion balance of sunflower.

Treatments	Root (g/kg)			Leaf (g/kg)			Flower disc (g/kg)		
	K^+/Na^+	Ca^{2+}/Na^+	P/Na^+	K^+/Na^+	Ca^{2+}/Na^+	P/Na^+	K^+/Na^+	Ca^{2+}/Na^+	P/Na^+
Non-AMF	13.47± 0.25c	4.08± 0.57c	1.14± 0.14d	98.34± 6.78c	50.52± 4.59c	7.41± 0.35c	61.12± 2.12d	22.01± 2.21d	9.32± 0.47d
AS	12.52± 0.23cd	5.05± 0.28b	1.30± 0.09c	95.46± 11.23c	74.16± 7.60ab	7.67± 0.89c	84.48± 2.15c	28.02± 2.53c	12.90± 0.62c
DS	21.24± 1.46a	5.28± 0.20ab	1.86± 0.07a	124.70± 14.69a	72.53± 7.07b	10.64± 1.21a	88.88± 6.54c	28.15± 2.28c	12.54± 0.42c
FM	11.83± 0.27d	3.98± 0.20c	1.26± 0.05c	114.55± 9.42b	73.43± 8.11b	8.29± 0.71b	95.86± 4.11b	39.84± 2.34a	16.72± 0.38b
DV	18.66± 0.33b	5.85± 0.75a	1.46± 0.11b	125.23± 4.25a	79.80± 3.21a	8.87± 0.12b	111.74± 6.43a	32.62± 1.08b	18.12± 0.81a

Note: Values followed by different letters in a column are significantly different among treatments at $P < 0.05$ level.

Correlation analysis

Correlation analysis showed that the mycorrhizal colonization was seriously correlated with root K, leaf K and Ca, and flower disc N content, which were highly and positively correlated with that of the root and leaf P and disc K content (Table 7). The results further showed that the mycorrhizal infestation could promote nutrient uptake and transport by the host plant sunflower.

Table 7. Relationship between root AMF colonization and mineral element contents in various organ of sunflower.

Organ	N	P	K	Ca	Mg
Root	0.09	0.70**	0.63*	0.39	0.08
Leaf	0.31	0.93**	0.59*	0.57*	0.47
Flower disc	0.62*	0.29	0.72**	-0.02	0.32

Note: *, $P < 0.05$; **, $P < 0.01$.

Discussion

In this study, four different AMF were able to colonize the ornamental sunflower roots, and typical AMF structures could be observed (Fig. 1), indicating that sunflower is not only an AM plant but also has a good symbiotic relationship with AMF. While mycorrhizal colonization of ornamental sunflower was highest in DS treatment, which may be related to the affinity between the strain and the host plant (Tian et al., 2004). The same plant has different affinity for different AMF, which leads to the difference of mycorrhizal infection, which has been confirmed on many plants such as trifoliate orange (Wu et al., 2016), tea (Shao et al., 2018), *Hyacinthus orientalis* (Xie et al., 2018), lily (Li et al., 2019), and tulip (Li et al., 2018).

In general, AMF infestation promotes host plant growth (Shao et al., 2018). The results of the present study showed that inoculation with AMF reduced the fresh weight in roots, stems (except DS) and leaves, but significantly increased the fresh weight of flower discs, which is similar to the results of Xie et al. (2018) in the study of different AMF on *Hyacinthus orientalis* growth, who reported that *Diversispora versiformis* reduced the biomass but *Funneliformis mosseae* significantly increased the stem fresh weight of *Hyacinthus orientalis*. This may be related to the fact that AMF infestation improved the distribution of organic matter and mineral elements in various organs of the plant. In addition, other studies have also shown that inoculation with *Glomus mosseae* (i.e. *Funneliformis mosseae*) and *Glomus intraradices* (i.e. *Rhizophagus intraradices*) had no significant effect on the biomass of artichoke flowers (Ceccarelli et al., 2010), suggesting that different AMF had different effects on the biomass of the host plant, and their related mechanisms need to be further investigated.

Mineral elements are extremely important for plant growth and development, they are the material basis, involved in plant morphological construction, synthesis and metabolism of organic substances, and plant resistance to adverse environmental conditions. In the present experiment, four different AMF increased the mineral element content of sunflower organs to different degrees, which is consistent with the results of previous studies on loquat (Zhang et al., 2012) and tea (Shao et al., 2018) seedlings, which mainly due to the large external hyphae enhanced the uptake of mineral nutrients by the host plant after AMF established a symbiotic relationship with the host plant (Liu et al., 2017). In addition, this may also be related to the ability of AMF external hyphae to secrete organic acids that activate insoluble nutrients, especially P, thus enhancing nutrient uptake and translocation efficiency (Javot et al., 2007).

The content and ratio of nutrients in each organ of plant reflect the nutrient demand of the plant and the ability to supply nutrients. N, P and K, as the large number of nutrients necessary for plant development, their ratios in different organs reflect the efficiency of their utilization by the plant and imply the limiting elements to which the plant growth and development are subjected at different developmental stages. In the present experiment, the N:P of sunflower organs ranged from 1.92 to 3.99, which is consistent with the results of Guo et al. (2018) on chestnut, Lin et al. (2020) on oat, and Wen et al. (2018) on *Leymus chinensis* in Horqin sands with N/P values <14, suggesting that the growth of sunflower is mainly

limited by N. However, sunflower root N:P was significantly reduced after inoculation with four different AMF, which may be due to (ⅰ) AMF increased the transfer efficiency of N in the root system to the above-ground parts (stem and leaf and flower disc), thus reducing the root N content; (ⅱ) AMF activated P in the soil and improved the uptake of P by sunflower roots, increasing the root P content and making N:P lower. In addition, the mean values of N:K in different organs of sunflower ranged from 0.15 to 0.415 and K:P ranged from 5.73 to 14.12, indicating that sunflower growth was not limited by K (Olde et al., 2003). This is in general agreement with the results of the growth study of *Myrica rubra* by Wu et al. (2019). This may be related to the fact that AMF infestation improved the nutrient status of the host plant.

It is well known that low Na^+ concentration can stimulate plant growth by regulating plant cell stretch and water balance, but high Na^+ concentration can cause protoplast crumpling and plastid wall separation. The results of this study showed that inoculation with four different AMF had no significant effect on the Na^+ content of sunflower roots (except FM) and leaves, but reduced the Na^+ concentration in sunflower discs to different degrees. This is in general agreement with the results of Wang (2020) who studied AMF on ion uptake by goatgrass, probably, AMF formed a mycorrhizal symbiosis with the plant, which increased the ability of the underground root part of the plant for Na^+ retention (Wang et al., 2020), thus reducing Na^+ concentration in sunflower discs to varying degrees. Whereas, FM significantly increased sunflower root but significantly decreased flower disc Na^+ concentration and content, which is consistent with the findings of Shen et al. (2004) on wild jujube that AMF may mitigate the toxic effects of Na^+ on sunflower aboveground to some extent by accumulating large amounts of Na^+ in the host plant root system (Shen et al., 2004).

K, an activator of many enzymes, is involved in several metabolic processes and has important functions in enhancing photosynthesis, improving plant resistance, and maintaining osmotic balance. Studies have shown that under adverse environmental conditions (drought stress, salt stress), the lower water content in the soil and thus the higher Na^+ concentration in the soil and plant disrupts the balance of various nutrients and cellular ions, reducing the K^+/Na^+ ratio (Zhou, 2019). However, under mycorrhizal conditions, AMF can selectively take up more K and Ca equivalent nutrients while helping the host plant to take up nutrients, thus avoiding the uptake of excess Na^+ (Hammer et al., 2011). Within the present study, four different AMF differentially affected the K^+/Na^+ and Ca^{2+}/Na^+ ratios in sunflower roots, leaves and discs, with DS and DV treatments significantly increasing the three ion ratios, which is the same as the results of Chang et al. (2018) on jujube, further confirming the selective effect of AMF on nutrient uptake in the environment.

In addition, AMF was able to induce the high-affinity K transporter protein (HKT) in the root system to maximize the segregation of Na^+ in the root system (Horie et al., 2009), which might be another important way to regulate the K^+ and Na^+ balance. Furthermore, the P/Na^+ ratio of sunflower organs was significantly increased after AMF inoculation, which may be related to the fact that AMF improved the P content of sunflower organs. On the one hand, AMF induced the expression of high-affinity P transporter proteins to increase P uptake, thus inhibiting the excess Na^+ uptake (Pfetffer et al., 2010). On the other hand, it may be that more P improved the hydration of the host plant cell structure and colloid binding water, enhancing the viscosity and elasticity of protoplasts and improving the resistance of protoplasts to local dehydration. Therefore, inoculation of AMF can effectively regulate ion homeostasis and help plants maintain normal physiological metabolism.

In conclusion, AMF can promote the growth and improve the ecological adaptation of ornamental sunflower by promoting the uptake of nutrients, regulating the distribution of each nutrient in each organ, and the balance between each departure.

Conflict of interest statement

Authors declare that they have no conflict of interest.

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References

Akbar Bethlenfalvay, G.J., Ames, R.N., 1987. Comparison of two methods for quantifying extraradical mycelium of vesicular-arbuscular mycorrhizal fungi. Soil Sci. Soc. Amer. J., 51(3): 125-134.

Ceccarelli, N., Curadi, M., Martelloni, L., Sbrana, C., Picciarelli, P., Giovannetti, M., 2010. Mycorrhizal colonization impacts on phenolic content and antioxidant properties of artichoke leaves and flower heads two years after field transplant. Plant Soil, 335(1-2): 311-323.

Chang, W., Sui, X., Fan, X.X., Jia, T.T., Song, F.Q., 2018. Arbuscular mycorrhizal symbiosis modulates antioxidant response and ion distribution in salt-stressed *Elaeagnus angustifolia* seedlings. Front. Microbiol., 9: 652.

Cheng, S., Li, Y., Wu, Q.S., 2002. Effects of root rot on the mycorrhizal growth of 'Newhall' Navel orange. South China Fruits, 49(4): 13-15.

Cramer, G.R., 2002. Sodium-Calcium interactions under salinity stress. USA: University of Nevada, Reno.

Fu, S.J., 2013. The improvement of AMF on plant growth and interception capability of vegetation-growing concrete. Heilongjiang: Harbin Institute of Technology.

Guo, S.J., Xie, M.M., Zhang, L., Sun, H.J. Song, Y., 2018. Temporal variation of C, N, P stoichiometric in fine roots of *Castanea mollissima*. J. Plant Nutr. Fert., 24(3): 825-832.

Hammer, E.C., Nasr, H., Pallon, J., Olsson, P.A., Wallander, H., 2011. Elemental composition of arbuscular mycorrhizal fungi at high salinity. Mycorrhiza, 21(2): 117-129.

Horie, T., Hauser, F., Schroeder, J.I., 2009. HKT transporter-mediated salinity resistance mechanisms in *Arabidopsis* and monocot crop plants. Trends Plant Sci., 14(12): 660-668.

Javot, H., Pumplin, N., Harrison, M.J., 2018. Phosphate in the arbuscular mycorrhizal symbiosis: transport properties and regulatory roles. Plant Cell Environ., 30(3): 310-322.

Li, W.B, Ning, C.H., Han, D.Y., Guo, S.X., 2019. A preliminary study on the mechanism of arbuscular mycorrhizal fungi prolonging the ornamental period of lily cut flowers. Mycosystema, 38(1): 107-116.

Li, W.B., Lu, W.Q., Xie, J.W., Liu, Y.M., Liu, R.J., Guo, S.X., 2018. Effects of arbuscular mycorrhizal fungi on the growth and cut flower physiology of *Tulipa gesneriana*. Mycosystema, 37(4): 456-465.

Lin, Z.L., Gao, Y., Zhu, T.X., Gao, K., 2020. Effects of nitrogen application rate and density on the stoichiometric characteristics of C, N, and P in oat leaves. Pratacult. Sci., 37(6): 1107-1114.

Liu, C.Y., Wu, Q.S., Zou, Y.N., 2017. Effects of arbuscular mycorrhizal fungi on phosphorous uptake and phosphatase release in trifoliate orange seedlings. Mycosystema, 36(7): 942-949.

Olde, V.H., Wassen, M.J., Verkroost, A.W.M., de, Ruiter, C.P., 2003. Species richness-productivity patterns differ between N-, P-, K-limited wetlands. Ecology, 84(8): 2191-2199.

Pfetffer, C.M., Bloss, H.E., 2010. Growth and nutrition of guayule (*Parthenium argentatum*) in a saline soil as influenced by vesicular-arbuscular mycorrhiza and phosphorus fertilization. New Phytol., 108(3): 315-321.

Phillips, J.M., Hayman, D.S., 1970. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Trans. British Mycol. Soc., 55: 158-161.

Qu, M.H., Yu, Y.C., Li, S., Zhang, J.C., 2019. Advances in research on activation of mineral nutrients by arbuscular mycorrhizal fungi. J. Zhejiang A&F Univ., 36(2): 394-405.

Shao, Y.D., Zhang, D.J., Hu, X.C., Wu, Q.S., Kamil, K., 2018. Mycorrhiza-induced changes in root growth and nutrient absorption of tea plants. Plant Soil Environ., 64: 283-289.

Shen, L.Y., Mao, Y.M., Lu, J.Y., Peng, S.Q., Li, X.L., Zhang, F.S., 2004. Effects of arbuscular mycorrhizae on salt tolerance of wild jujube (*Zizyphus spinosus* Hu) seedlings. Acta Pedol. Sin., 41(3): 426-433.

Tian, C.Y., Feng, G., Li, X.L., Zhang, F.S., 2004. Different effects of arbuscular mycorrhizal fungal isolates from saline or non-saline soil on salinity tolerance of plants. Appl. Soil Ecol., 26(2): 143-148.

Wang, Y.K., Yang, Y.R., Wang, D.L., 2020. Effects of arbuscular mycorrhiza al fungi on ion absorption and distribution in *Leymus chinensis* under saline-alkaline stress. Acta Pratacult. Sin., 29(12): 95-104.

Wen, C., Shan, Y.M., Jia, W.X., Gao, L.J., Yang, X.S., Siriguleng, Zhang, J., Liu, Y.Z., 2018. Effect of bio-fertilizers on vegetation characteristics and stoichiometry of *Camellia chinensis*. Pratacult. Sci., 35(9): 2192-2200.

Wu, J.S., Jiang, Z.L., Lü, A.H., Ye, L.X., Wang, Z.,

Zhou, B.Z., Wang, X.X., Zhang, Y., 2019. The ecological stoichiometry of N, P and K in organs of *Myrica rubra* of different ages. Acta Agricult. Univ. Jiangxiensis, 41(3): 447-453.

Wu, Q.S., Liu, C.Y., Zhang, D.J., Zou, Y.N., He, X.H., Wu, Q.H., 2016. Mycorrhiza alters the profile of root hairs in trifoliate orange. Mycorrhiza, 26: 237-247.

Xie, M.M., Wu, Q.S., 2018. Arbuscular mycorrhizal fungi regulate flowering of *Hyacinths orientalis* L. Anna marie. Emirates J. Food Agric., 30(2): 144-149.

Zhang, Y., Li, J., Yao, Q., Chen, J.Z., Hu, Y.L., Liu, X.Y., Huang, Y.J., 2012. Effects of arbuscular mycorrhizal fungi on growth and nutrient uptake of *Eriobotrya japonica* plants under different water regimes. Acta Horticult. Sin., 39(4): 757-762.

Zhou, X.N., 2019. Effects of arbuscular mycorrhizal fungi on growth and salt and alkali tolerance of sunflower. Neimenggu: Mongolian University.

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