Effects of Different Seed Stem Sizes on the Changes of Available Elements in Rhizosphere Soil of *Fritillaria thunbergii* Miq.

Yong PENG[1], Rui PAN[2], Zhengyan LIU[1], Xiaohong WU[3], Nong ZHOU[3], Wenwu YANG[4 *]

1. Qijing District State Forest Farm, Chongqing 401420, China; 2. Chongqing Academy of Chinese Materia Medica, Chongqing 400065, China; 3. College of Biological and Food Engineering/Chongqing Engineering Laboratory for Green Cultivation and Deep Processing of the Three Gorges Reservoir Area's Medicinal Herbs, Chongqing Three Gorges University, Chongqing 404120, China; 4. Chongqing Wangzhou Food and Drug Inspection Institute/Chongqing Key Laboratory of Development and Utilization of Genuine Medicinal Materials in Three Gorges Reservoir Area, Chongqing 404000, China

Abstract [**Objectives**] This study was conducted to screen suitable seed stems of *Fritillaria thunbergii* Miq. from different provenances and to provide a theoretical basis for the high-yielding and high-efficiency cultivation of *F. thunbergii* Miq. introduced to different places. [**Methods**] *F. thunbergii* Miq. from four different provenances including Zhejiang, Nantong and Chongqing were introduced and cultivated in Wanzhou of Chongqing. The contents of available Zn, Fe, Mn, Cu, Mo, N, P, K, Ca and Mg in rhizosphere soil of *F. thunbergii* Miq. during five growing stages were determined after selecting different stem sizes for field cultivation. [**Results**] Small stems of Pan'an and Ningbo provenances (SSG3, 121 – 160/kg) and middle stems of Nantong and Fengjie provenances (SSG2, 81 – 120/kg) showed higher soil availability. [**Conclusions**] In the process of introduction and cultivation of *F. thunbergii* Miq., high yield and high efficiency can be achieved by selecting smaller seed stems of *F. thunbergii* Miq.

Key words *Fritillaria thunbergii* Miq.; Different provenances; Stem size; Introduction; Cultivation; Soil nutrient element; Availability
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Fritillaria thunbergii Miq. has good effects in eliminating phlegm, relieving cough, subsiding swelling, removing stasis, clearing away heat and reducing fire, and serves as a main medicinal material for treating diseases of the lung meridian. It is a herb of *Fritillaria* in Liliaceae included in *Chinese Pharmacopoeia*[1]. *F. thunbergii* Miq. is native to Ningbo, Zhejiang Province, with a long cultivation history and significant medicinal value. At present, *F. thunbergii* Miq. is mainly produced by artificial cultivation, and concentrated in coastal areas such as Zhejiang and Fujian. In recent years, introduction and domestication cultivation have appeared in Fengjie, Chongqing[2]. However, there is still a lack of systematic high-yield and high-quality cultivation techniques after introduction and cultivation. Therefore, it is an urgent problem to reduce the planting cost and improve the yield and quality of *F. thunbergii* Miq. after introduction. The yield of *F. thunbergii* Miq. is closely related to the seed source and soil nutrients[3], and the accumulation and consumption of organic matter at different growth and development stages directly affect its yield and quality. Reasonable fertilization can effectively improve the formation of the biomass and quality of *F. thunbergii* Miq. At present, there have been few studies on the relationship between the stem size of *F. thunbergii* Miq. and the content of available nutrient elements in rhizosphere soil. In this study, with *F. thunbergii* Miq. from four different provenances of Ningbo and Pan'an of Zhejiang Province, Nantong of Jiangsu Province and Fengjie, Chongqing City as research objects, the availability of macroelements (N, P and K), medium elements (Ca, Mg) and microelements (Zn, Fe, Mn, Cu and Mo) were measured in rhizosphere soil to explore the relationship between provenance and stem size, and soil nutrient availability, aiming to provide a theoretical reference for the scientific introduction and cultivation of *F. thunbergii* Miq. and the improvement of its yield and quality.

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Yong PENG (1985 –), male, P. R. China, forest engineer, devoted to plant cultivation.
* Corresponding author.

Materials and Methods

Experiment materials

Seed bulbs used for sowing were collected from four planting bases of *F. thunbergii* Miq., namely Qianxiang in Ningbo, Xinwu in Pan'an, Zhangzhishan in Nantong and Fengping in Fengjie. Full healthy bulbs with tight scales and free of pests and diseases were chosen.

Reagents and equipment

Calcium (Ca, batch number: GSB04-1720-2004), magnesium (Mg, batch number: GSB04-1735-2004), manganese (Mn, batch number: GSB04-1736-2004), iron (Fe, batch number: GSB04-1726-2004), copper (Cu, batch number: GSB04-1725-2004), zinc (Zn, batch number: GSB04-1761-2004), molybdenum (Mo, batch number: GSB04-1737-2004) and germanium (Ge, batch number: GSB04-1728-2004), all purchased from National Analysis and Testing Center for Nonferrous Metals and Electronic Materials; high-purity nitric acid (MOS grade), purchased from Beijing Chemical Works Co., Ltd.

Plasma mass spectrometer (ICP-MS) (EXPEC 7000 Hangzhou Focused Photonics, Inc.); ultraviolet spectrophotometer (Thermo, Nano Drop 2000); electronic analytical balance (FA2104B, Yueping, Shanghai); constant-temperature gas bath oscillator (THZ-82A, Jiangsu Jincheng Guosheng); atomic absorption spectrophotometer (TAS-990, Shanghai METASH); flame photometer (FP640, Shanghai Spectroscopic Instrument).

Experimental methods

Bulbs of *F. thunbergii* Miq. from different provenances were cultivated in the open field in Wanzhou District, Chongqing. Weeding and ploughing were performed before planting. Organic compound fertilizer with organic matter ≥45%, containing no N, P and K, was applied. The row spacing of the planted plants was 15 cm × 25 cm, and bulbs of *F. thunbergii* Miq. from four different provenances were divided into three seed stem treatment groups according to the bulb size: SSG1 (big shellfish, ≤80/kg), SSG2 (middle shellfish, 81 – 120/kg) and SSG3 (small shellfish, 121 – 160/kg), and randomized block design was adopted with three replicates. Daily field maintenance, water and fertilizer management and pest control were carried out during the growth period of *F. thunbergii* Miq.

Determination methods

Diethylenetriamine pentaacetic acid (DTPA) was used to extract available trace elements such as Zn, Fe, Mn, Cu and Mo, and their contents were determined by ICP-MS[4]. Exchangeable Ca and Mg in soil were extracted by ammonium acetate solution (1 mol/L, pH 7.0), and the contents of the extract were determined by atomic absorption spectrophotometer[5]. The leaching and content determination of available N, P and K were carried out according to the method of Bao[6].

Data analysis

SPSS 20.0 was used for statistical difference test ($P < 0.05$ significant difference, $P < 0.01$ extremely significant difference), and excel was used for data processing.

Results and Analysis

Analysis of available elements in rhizosphere soil of *F. thunbergii* Miq. from Nantong, Jiangsu Province

Bulbs of *F. thunbergii* Miq. from Nantong, Jiangsu Province with three different stem sizes were cultivated in the same habitat. Table 1 shows the availability of 10 conventional nutrient elements in rhizosphere soil at different development stages. At the early stage of emergence, the highest contents of available N, P, K, Mg, Zn and Cu were observed in group SSG2, and the highest contents of Ca, Fe, Mn and Mo were in group SSG3. At the seedling stage, group SSG1 showed the highest contents of N, P, K and Cu, and the content of Ca was the highest in group SSG3, and group SSG2 exhibited the highest contents of Mg, Zn, Fe, Mn and Mo. At the flowering stage, group SSG3 showed the highest contents of N, Ca, Mn and Mo, and the contents of available P, K and Mg were the highest in group SSG1. During bulb expansion, the contents of P, Ca, Zn, Mn, Cu and Mo in group SSG1 were the highest, and the contents of N, K, Mg and Fe in group SSG2 were the highest. At the harvesting stage, the contents of P, K, Ca, Zn, Fe and Mn were the highest in group SSG1, and the contents of N, Mg and Mo were the highest in group SSSG2, which was statistically significant ($P < 0.05$).

When introduced and cultivated with different stem sizes, the average contents of available elements in rhizosphere soil were N 91.856 mg/kg, P 53.159 mg/kg, K 109.528 mg/kg, Ca 17.822 mg/kg, Mg 1.657 mg/kg, Zn 0.317 mg/kg, Fe 9.744 mg/kg, Mn 3.862 mg/kg, Cu 0.755 mg/kg, and Mo 0.018 mg/kg, respectively. For group SSG2, the average available contents of N, P, K, Ca, Mg, Zn, Fe, Mn, Cu and Mo were 90.533, 63.947, 131.056g, 15.892, 1.974, 0.332, 10.972, 4.008, 0.675 and 0.018 mg/kg, respectively.

On the whole, the available content of elements in the three stem size treatments ranked as SSG2 > SSG1 > SSG3. The available contents of P, K, Mg, Fe and Mn in group SSG2 were the highest among the three groups, and they were 15.518% – 59.172%, 9.745% – 67.783%, 21.662% – 43.555%, 14.392% – 26.575% and 4.905 – 6.652% higher, respectively.

Analysis of available elements in rhizosphere soil of *F. thunbergii* Miq. from Pan'an, Zhejiang Province Bulbs of *F. thunbergii* Miq. from Pan'an, Zhejiang Province with three different stem sizes were cultivated in the same habitat. Table 2 shows the available contents of 10 conventional nutrient elements at different development stages. At the early stage of emergence, the contents of available N, P, K, Mg, Zn, Fe, Mn, Cu and Mo were the highest in group SSG1, and the content of Ca was the highest in group SSG2. At the seedling stage, the contents of available N, K, Ca, Mg and Mn in group SSG2 were higher than those in other two groups, and the contents of P, Zn and Mo in group SSG1 were significantly higher than those in groups SSG2 and SSG3 ($P < 0.05$). At the flowering stage, the available contents of N, P, K, Mg, Zn, Fe, Mn and Cu in group SSG1 were significantly higher than those in other two groups ($P < 0.05$), and the highest content of Ca was observed in group SSG3, and the available Mo contents in groups SSG1 and SSG2 were significantly higher than those in group SSG3. At the harvesting stage, the contents of available Fe, Mn, Cu and Mo in SSG2 were significantly higher than those in other two groups ($P < 0.05$), and the content of available Zn was the highest in group SSG3.

The available contents of elements in groups SSG1, SSG2 and SSG3 ranked as SSG3 > SSG2 > SSG1. The available contents of N, P, K, Ca, Mg, Zn, Fe, Mn, Cu and Mo in group SSG3 were 100.520, 54.487, 93.117, 14.741, 1.740, 0.461, 10.163, 3.485, 0.894 and 0.019 mg/kg, respectively. The available contents of P, K, Mg, Zn, Fe and Cu in group SSG3 were all highest, and they were 9.702% – 38.046%, 11.299% – 52.540%, 6.293% – 22.781%, 33.535% – 33.585%, 8.440% – 12.278% and 1.800% – 4.858% higher, respectively.

Table 1 Effects of different stem sizes on available contents of 10 nutrient elements in rhizosphere soil of *F. thunbergii* from Nantong ($\bar{x} \pm s$, $n=3$)

mg/kg

Element	Treatment	Early stage of emergence	Seedling stage	Flowering stage	Bulb expansion stage	Harvesting stage
N	SSG1	98.700 ± 3.786 a	112.467 ± 1.229 a	72.683 ± 6.146 b	80.383 ± 5.448 c	82.600 ± 7.580 a
	SSG2	107.100 ± 8.930 a	87.850 ± 2.450 b	64.633 ± 3.156 b	108.850 ± 1.750 a	84.233 ± 4.966 a
	SSG3	103.600 ± 8.930 a	110.717 ± 4.459 a	99.867 ± 3.523 a	94.150 ± 2.129 b	70.000 ± 4.735 b
P	SSG1	51.011 ± 0.680 b	68.379 ± 0.359 a	58.385 ± 0.108 a	51.084 ± 0.255 b	47.922 ± 0.643 a
	SSG2	97.908 ± 1.077 a	63.718 ± 0.218 a	43.557 ± 0.141 b	69.198 ± 0.286 a	45.352 ± 0.071 b
	SSG3	42.329 ± 0.072 c	60.984 ± 13.097 a	38.913 ± 0.108 c	22.696 ± 0.403 c	35.951 ± 0.180 c
K	SSG1	137.358 ± 3.309 b	353.569 ± 1.986 a	37.052 ± 1.081 a	50.780 ± 0.936 b	18.332 ± 0.540 b
	SSG2	272.139 ± 1.986 a	295.070 ± 1.324 b	13.341 ± 0.936 c	52.964 ± 0.540 a	21.764 ± 0.001 a
	SSG3	95.395 ± 2.859 c	227.992 ± 1.948 c	18.644 ± 0.540 b	37.364 ± 0.540 c	11.157 ± 1.081 c
Ca	SSG1	15.269 ± 0.344 b	18.722 ± 0.167 b	15.713 ± 0.144 c	17.658 ± 0.203 a	22.031 ± 0.370 a
	SSG2	8.931 ± 0.713 c	18.219 ± 0.272 b	16.471 ± 0.017 b	14.452 ± 0.362 b	21.388 ± 0.062 a
	SSG3	21.126 ± 0.168 a	20.172 ± 0.123 a	18.928 ± 0.001 a	17.577 ± 0.265 a	20.667 ± 0.193 b
Mg	SSG1	1.280 ± 0.001 c	1.616 ± 0.004 b	1.784 ± 0.001 a	2.047 ± 0.001 b	1.384 ± 0.007 b
	SSG2	2.552 ± 0.001 a	1.896 ± 0.004 a	1.725 ± 0.006 b	2.152 ± 0.009 a	1.543 ± 0.020 a
	SSG3	1.322 ± 0.007 b	1.506 ± 0.012 c	1.419 ± 0.005 c	1.328 ± 0.013 c	1.299 ± 0.008 c
Zn	SSG1	0.258 ± 0.001 b	0.165 ± 0.002 b	0.575 ± 0.005 a	0.071 ± 0.003 a	0.647 ± 0.009 a
	SSG2	0.359 ± 0.002 a	0.173 ± 0.002 a	0.485 ± 0.007 b	0.055 ± 0.004 b	0.589 ± 0.004 b
	SSG3	0.241 ± 0.002 c	0.118 ± 0.002 c	0.487 ± 0.004 b	0.025 ± 0.001 c	0.509 ± 0.002 c
Fe	SSG1	10.176 ± 0.079 b	10.041 ± 0.039 b	12.649 ± 0.064 c	4.558 ± 0.016 b	10.533 ± 0.044 a
	SSG2	9.599 ± 0.028 c	12.600 ± 0.038 a	17.145 ± 0.030 a	5.443 ± 0.029 a	10.072 ± 0.028 b
	SSG3	10.411 ± 0.039 a	9.232 ± 0.027 c	12.820 ± 0.025 b	3.001 ± 0.078 c	7.877 ± 0.021 c
Mn	SSG1	1.306 ± 0.003 b	4.571 ± 0.026 b	4.930 ± 0.030 c	2.336 ± 0.021 a	5.648 ± 0.031 a
	SSG2	1.256 ± 0.003 c	6.030 ± 0.043 a	5.244 ± 0.024 b	2.225 ± 0.007 b	5.286 ± 0.019 b
	SSG3	1.576 ± 0.008 a	4.272 ± 0.036 c	6.530 ± 0.069 a	1.879 ± 0.050 c	4.847 ± 0.056 c
Cu	SSG1	0.413 ± 0.001 b	0.268 ± 0.003 a	1.145 ± 0.008 a	0.078 ± 0.004 a	2.150 ± 0.042 a
	SSG2	0.422 ± 0.004 a	0.264 ± 0.003 a	0.702 ± 0.011 c	0.053 ± 0.002 b	1.932 ± 0.022 b
	SSG3	0.408 ± 0.005 b	0.244 ± 0.001 b	1.024 ± 0.013 b	0.046 ± 0.001 c	2.178 ± 0.017 a
Mo	SSG1	0.026 ± 0.001 b	0.016 ± 0.001 c	0.023 ± 0.002 a	0.007 ± 0.001 a	0.018 ± 0.001 b
	SSG2	0.023 ± 0.001 c	0.019 ± 0.001 a	0.023 ± 0.001 a	0.006 ± 0.001 a	0.019 ± 0.001 a
	SSG3	0.028 ± 0.001 a	0.017 ± 0.001 b	0.026 ± 0.001 a	0.005 ± 0.001 b	0.015 ± 0.001 c

Table 2 Effects of different stem sizes on available contents of 10 nutrient elements in rhizosphere soil of *F. thunbergii* Miq. from Pan'an ($\bar{x} \pm s$, $n=3$)

mg/kg

Element	Treatment	Early stage of emergence	Seedling stage	Flowering stage	Bulb expansion stage	Harvesting stage
N	SSG1	113.400 ± 2.865 a	109.900 ± 3.051 b	109.317 ± 5.448 a	82.600 ± 3.500 b	87.383 ± 7.344 a
	SSG2	110.717 ± 1.796 a	123.667 ± 4.348 a	94.383 ± 2.110 b	98.933 ± 8.953 a	80.383 ± 1.415 ab
	SSG3	101.150 ± 1.526 b	70.933 ± 3.018 c	84.817 ± 5.266 c	69.767 ± 5.346 c	72.683 ± 6.146 b
P	SSG1	67.351 ± 0.109 a	68.379 ± 0.359 a	49.686 ± 0.108 a	43.739 ± 0.758 b	43.281 ± 1.099 a
	SSG2	51.584 ± 0.109 b	63.718 ± 0.218 b	42.426 ± 0.071 b	49.832 ± 0.364 a	40.783 ± 3.029 a
	SSG3	41.780 ± 0.219 c	60.984 ± 13.097 b	27.221 ± 0.071 c	34.056 ± 0.532 c	33.310 ± 0.465 b
K	SSG1	156.077 ± 0.662 a	235.480 ± 3.287 a	15.524 ± 0.540 a	40.172 ± 0.540 a	18.332 ± 0.540 a
	SSG2	119.418 ± 1.948 b	237.975 ± 0.001 a	8.661 ± 0.936 b	35.492 ± 0.540 b	16.772 ± 0.540 b
	SSG3	106.314 ± 2.162 c	170.117 ± 1.986 b	3.981 ± 0.001 c	18.956 ± 0.001 c	5.853 ± 0.936 c
Ca	SSG1	13.580 ± 0.054 ab	14.542 ± 0.252 a	15.230 ± 0.159 b	14.552 ± 0.238 a	15.800 ± 0.238 ab
	SSG2	13.920 ± 0.444 a	14.901 ± 0.009 a	16.040 ± 0.069 a	14.370 ± 0.210 a	15.057 ± 0.388 b
	SSG3	13.035 ± 0.102 b	13.891 ± 0.062 b	16.181 ± 0.184 a	14.733 ± 0.018 a	16.182 ± 0.034 a
Mg	SSG1	1.894 ± 0.003 a	1.584 ± 0.004 b	1.699 ± 0.005 a	1.708 ± 0.017 a	1.814 ± 0.007 a
	SSG2	1.470 ± 0.011 c	1.669 ± 0.017 a	1.592 ± 0.004 b	1.730 ± 0.003 a	1.723 ± 0.016 b
	SSG3	1.543 ± 0.007 b	1.454 ± 0.004 c	1.181 ± 0.001 c	1.600 ± 0.001 b	1.307 ± 0.003 c
Zn	SSG1	0.307 ± 0.001 a	0.153 ± 0.001 a	1.117 ± 0.008 a	0.057 ± 0.001 a	0.669 ± 0.012 c
	SSG2	0.258 ± 0.001 b	0.094 ± 0.001 c	0.537 ± 0.007 b	0.055 ± 0.001 a	0.780 ± 0.010 b
	SSG3	0.195 ± 0.001 c	0.125 ± 0.007 b	0.500 ± 0.006 c	0.035 ± 0.001 b	0.872 ± 0.006 a

(Continued)

(Table 2)

Element	Treatment	Early stage of emergence	Seedling stage	Flowering stage	Bulb expansion stage	Harvesting stage
Fe	SSG1	13.186 ±0.046 a	9.560 ±0.037 b	12.543 ±0.065 a	5.769 ±0.041 c	9.757 ±0.031 b
	SSG2	9.076 ±0.065 c	6.058 ±0.035 c	12.253 ±0.022 b	6.455 ±0.056 a	13.018 ±0.023 a
	SSG3	9.463 ±0.027 b	10.225 ±0.012 a	10.165 ±0.013 c	5.998 ±0.051 b	9.407 ±0.056 c
Mn	SSG1	1.737 ±0.007 a	3.217 ±0.003 b	6.631 ±0.084 a	1.972 ±0.071 b	3.870 ±0.057 b
	SSG2	1.209 ±0.001 b	2.367 ±0.017 c	5.456 ±0.018 b	2.588 ±0.023 a	6.221 ±0.035 a
	SSG3	1.038 ±0.005 c	3.630 ±0.010 a	4.112 ±0.014 c	1.822 ±0.057 c	3.538 ±0.022 c
Cu	SSG1	0.425 ±0.002 a	0.264 ±0.001 b	1.135 ±0.026 a	0.179 ±0.001 a	2.465 ±0.012 c
	SSG2	0.363 ±0.002 b	0.202 ±0.002 c	0.848 ±0.004 c	0.132 ±0.001 c	2.844 ±0.052 a
	SSG3	0.364 ±0.002 b	0.287 ±0.004 a	0.892 ±0.001 b	0.141 ±0.001 b	2.577 ±0.022 b
Mo	SSG1	0.029 ±0.001 a	0.015 ±0.001 a	0.023 ±0.001 a	0.009 ±0.001 c	0.019 ±0.001 b
	SSG2	0.025 ±0.001 c	0.009 ±0.001 b	0.023 ±0.001 a	0.011 ±0.001 b	0.047 ±0.001 a
	SSG3	0.026 ±0.001 b	0.015 ±0.001 a	0.019 ±0.002 b	0.012 ±0.001 a	0.017 ±0.001 c

Table 3 Effects of different stem sizes on available contents of 10 nutrient elements in rhizosphere soil of *F. thunbergii* Miq. from Ningbo ($\bar{x} \pm s$, $n=3$)

mg/kg

Element	Treatment	Early stage of emergence	Seedling stage	Flowering stage	Bulb expansion stage	Harvesting stage
N	SSG1	74.550 ±1.400 b	94.267 ±3.541 a	94.967 ±1.578 a	94.500 ±5.888 a	69.767 ±4.904 a
	SSG2	52.500 ±4.036 c	80.267 ±3.643 b	82.483 ±4.087 b	88.550 ±2.990 a	45.267 ±4.087 b
	SSG3	105.933 ±2.627 a	86.217 ±4.778 ab	100.217 ±4.376 a	78.983 ±2.627 b	47.600 ±0.700 b
P	SSG1	46.050 ±0.286 b	37.518 ±0.143 a	40.658 ±0.324 a	38.874 ±0.472 b	50.350 ±0.257 a
	SSG2	24.033 ±0.109 c	26.391 ±0.371 c	36.603 ±0.248 b	34.316 ±0.286 c	44.971 ±0.812 c
	SSG3	48.221 ±0.109 a	32.073 ±0.572 b	35.660 ±0.041 c	39.795 ±0.178 a	49.184 ±0.109 b
K	SSG1	135.018 ±1.324 a	76.675 ±4.711 b	11.157 ±0.540 a	21.140 ±0.540 a	7.725 ±0.936 a
	SSG2	115.362 ±3.971 b	92.275 ±3.009 a	8.973 ±0.540 b	19.580 ±0.540 b	5.229 ±0.540 a
	SSG3	120.510 ±4.639 b	85.723 ±3.009 a	9.909 ±0.540 b	16.772 ±0.540 c	6.789 ±0.001 a
Ca	SSG1	7.154 ±0.067 a	8.231 ±0.072 a	7.803 ±0.212 a	8.061 ±0.185 a	6.429 ±0.096 b
	SSG2	6.830 ±0.295 ab	7.296 ±0.068 b	6.239 ±0.109 b	6.183 ±0.099 c	7.028 ±0.045 a
	SSG3	6.459 ±0.023 b	7.334 ±0.014 b	6.524 ±0.045 b	6.749 ±0.111 b	6.486 ±0.034 b
Mg	SSG1	1.429 ±0.011 a	1.459 ±0.010 a	1.415 ±0.006 a	1.461 ±0.004 a	1.320 ±0.005 a
	SSG2	1.147 ±0.007 c	1.265 ±0.007 c	1.263 ±0.019 b	1.234 ±0.002 c	1.268 ±0.004 b
	SSG3	1.368 ±0.006 b	1.388 ±0.007 b	1.238 ±0.016 b	1.447 ±0.003 b	1.323 ±0.016 a
Zn	SSG1	0.255 ±0.003 a	0.093 ±0.001 a	0.677 ±0.018 b	0.035 ±0.003 a	0.537 ±0.006 c
	SSG2	0.193 ±0.003 b	0.088 ±0.001 b	0.736 ±0.004 a	0.024 ±0.001 b	0.968 ±0.009 a
	SSG3	0.197 ±0.005 b	0.087 ±0.003 b	0.671 ±0.006 b	0.020 ±0.001 c	0.629 ±0.008 b
Fe	SSG1	63.535 ±0.043 a	42.509 ±0.082 c	54.087 ±0.061 c	13.666 ±0.055 b	33.839 ±0.070 c
	SSG2	55.677 ±0.045 b	52.386 ±0.097 a	73.337 ±0.087 a	14.027 ±0.078 a	52.317 ±0.097 a
	SSG3	42.996 ±0.064 c	49.470 ±0.018 b	69.965 ±0.098 b	12.462 ±0.034 c	45.189 ±0.058 b
Mn	SSG1	3.131 ±0.053 a	7.867 ±0.025 a	13.835 ±0.045 a	2.901 ±0.014 a	8.134 ±0.069 a
	SSG2	2.222 ±0.036 b	5.556 ±0.046 c	11.681 ±0.070 c	2.670 ±0.010 b	6.638 ±0.034 c
	SSG3	1.642 ±0.020 c	6.832 ±0.096 b	12.939 ±0.008 b	2.242 ±0.027 c	7.221 ±0.039 b
Cu	SSG1	0.486 ±0.007 a	0.233 ±0.001 b	1.316 ±0.051 c	0.109 ±0.009 a	2.179 ±0.025 c
	SSG2	0.314 ±0.006 b	0.212 ±0.008 c	1.508 ±0.009 a	0.095 ±0.001 b	4.429 ±0.009 a
	SSG3	0.277 ±0.007 c	0.246 ±0.002 a	1.405 ±0.044 b	0.060 ±0.002 c	2.370 ±0.040 b
Mo	SSG1	0.053 ±0.001 a	0.033 ±0.001 b	0.057 ±0.001 b	0.023 ±0.001 a	0.030 ±0.001 c
	SSG2	0.049 ±0.001 b	0.040 ±0.001 a	0.070 ±0.001 a	0.019 ±0.001 b	0.047 ±0.001 a
	SSG3	0.045 ±0.001 c	0.040 ±0.000 a	0.069 ±0.001 a	0.019 ±0.001 b	0.045 ±0.001 b

Analysis of available elements in rhizosphere soil of *F. thunbergii* Miq. from Ningbo, Zhejiang Province Bulbs of *F. thunbergii* Miq. from Ningbo, Zhejiang Province with three different stem sizes were cultivated in the same habitat. Table 3 shows the available contents of 10 conventional nutrient elements. At the early stage of emergence, group SSG3 showed high contents of N and P, and the available contents of K, Ca, Mg, Zn, Fe, Mn, Cu and Mo were the highest in group SSG1 ($P<0.05$). At the seedling stage, the available contents of N, P, Ca, Mg, Zn and Mn were the highest in group SSG1. At the flowering stage, the available contents of P, K, Ca, Mg and Mn were the highest in group SSG1, and group SSG1 also showed higher available contents of Zn, Fe, Cu and Mo. At the stage of bulb expansion, the contents of N, K, Ca, Mg, Zn, Mn, Cu and Mo in group SSG1 were significantly higher than those in groups SSG2 and SSG3 ($P<0.05$). At the harvesting stage, group SSG1 showed higher N, P, K and Mn contents, and the contents of available Zn, Fe, Cu and Mo in group SSG2 were significantly higher than those in groups SSG1 and SSG3 ($P<0.05$).

The available contents of elements in groups SSG1, SSG2 and SSG3 ranked as SSG3 > SSG2 > SSG1. The average contents of available N, P, K, Ca, Mg, Zn, Fe, Mn, Cu and Mo in group SSG3 were 85.610, 42.690, 50.343, 7.536, 1.417, 0.319, 41.527, 7.174, 0.865 and 0.039 mg/kg, respectively. Group SSG3 exhibited highest contents of available N, P, K, Ca, Mg and Cu among the groups, and the values were 2.172% – 22.627%, 4.156% – 28.342%, 4.265% – 5.011%, 12.217% – 12.297%, 4.731% – 14.684% and 16.168% – 24.685% higher, respectively.

Analysis of available elements in rhizosphere soil of *F. thunbergii* Miq. from Fengjie, Chongqing Bulbs of *F. thunbergii* Miq. from Fengjie, Chongqing with three different stem sizes were cultivated in the same habitat. Table 4 shows the available contents of 10 nutrient elements. At the early stage of emergence, group SSG1 showed highest available contents of elements K, Ca, Mg, Zn and Cu. At the seedling stage, the highest contents of available forms of elements N, P, Fe, Mn, Cu and Mo were all observed in cultivation group SSG2. At the flowering stage, the contents of available N, P, K, Zn, Fe, Mn and Mo in group SSG3 were significantly higher than those in groups SSG1 and SSG2, while the highest Cu content was observed in group SSG2, and the highest Ca and Mg contents were in group SSG1. In the bulb expansion stage, except for Ca, Mg and Cu which were the highest in SSG1, the available contents of P, Zn, Fe, Mn and Mo were all highest in group SSG3. At the harvesting stage, the contents of P, Ca, Mg and Zn were the highest in group SSG1, and the contents of available N, Fe, Mn, Cu and Mo were all highest in group SSG2.

The available contents of elements in groups SSG1, SSG2 and SSG3 showed an order of SSG2 > SSG3 > SSG1. The available contents of the 10 elements in SSG2 were as follows: N 100.730 mg/kg, P 34.534 mg/kg, K 33.059 mg/kg, Ca 8.058 mg/kg, Mg 1.335 mg/kg, Zn 0.388 mg/kg, Fe 46.097 mg/kg, Mn 6.374 mg/kg, Cu 1.047 mg/kg, and Mo 0.044 mg/kg. Among the groups, group SSG2 showed highest contents of available N, Fe, Mn, Cu, and Mo, which were 12.539% – 18.729%, 2.665% – 39.862%, 23.756% – 26.372%, 12.361% – 21.232% and 13.472% – 31.928% higher, respectively.

Table 4 Effects of different stem sizes on available contents of 10 nutrient elements in rhizosphere soil of *F. thunbergii* Miq. from Fengjie ($\bar{x} \pm s$, $n=3$)

mg/kg

Element	Treatment	Early stage of emergence	Seedling stage	Flowering stage	Bulb expansion stage	Harvesting stage
N	SSG1	78.867 ± 0.729 c	85.400 ± 0.700 b	97.067 ± 5.658 a	100.100 ± 6.102 ab	62.767 ± 4.087 b
	SSG2	146.533 ± 2.110 a	93.100 ± 1.750 a	77.467 ± 8.439 b	102.900 ± 2.778 a	83.650 ± 8.231 a
	SSG3	94.733 ± 2.021 b	83.067 ± 0.535 b	100.100 ± 1.750 a	92.867 ± 3.676 b	76.767 ± 4.102 a
P	SSG1	36.818 ± 0.286 b	35.972 ± 0.041 b	28.494 ± 0.141 b	29.994 ± 0.108 c	38.974 ± 0.834 a
	SSG2	28.541 ± 0.367 c	38.255 ± 0.180 a	34.246 ± 0.567 a	33.607 ± 0.427 b	38.022 ± 0.904 a
	SSG3	37.510 ± 0.219 a	30.052 ± 0.082 c	34.646 ± 0.141 a	41.495 ± 0.216 a	30.287 ± 0.842 b
K	SSG1	92.587 ± 2.859 a	56.084 ± 3.009 a	2.733 ± 0.540 b	14.276 ± 0.936 b	0.705 ± 0.662 b
	SSG2	83.539 ± 2.647 b	54.524 ± 2.476 a	6.477 ± 0.540 a	18.956 ± 0.001 a	1.797 ± 0.540 ab
	SSG3	74.179 ± 1.324 c	57.332 ± 1.324 a	7.101 ± 0.540 a	18.644 ± 0.540 a	3.045 ± 0.936 a
Ca	SSG1	9.465 ± 0.286 a	10.334 ± 0.167 a	9.621 ± 0.022 a	9.079 ± 0.038 a	9.614 ± 0.005 a
	SSG2	8.369 ± 0.209 b	8.268 ± 0.310 b	7.814 ± 0.019 b	8.164 ± 0.156 b	7.674 ± 0.018 b
	SSG3	8.300 ± 0.083 b	8.150 ± 0.048 b	7.188 ± 0.067 c	7.557 ± 0.085 c	7.292 ± 0.271 b
Mg	SSG1	1.622 ± 0.005 a	1.476 ± 0.006 a	1.602 ± 0.004 a	1.770 ± 0.003 a	1.548 ± 0.007 a
	SSG2	1.402 ± 0.008 b	1.004 ± 0.006 b	1.380 ± 0.016 b	1.586 ± 0.006 b	1.305 ± 0.006 b
	SSG3	1.403 ± 0.002 b	0.972 ± 0.006 c	1.307 ± 0.015 c	1.511 ± 0.005 c	1.268 ± 0.004 c
Zn	SSG1	0.252 ± 0.003 a	0.208 ± 0.001 a	0.557 ± 0.007 c	0.035 ± 0.001 b	1.285 ± 0.030 a
	SSG2	0.229 ± 0.005 b	0.194 ± 0.003 b	0.684 ± 0.008 b	0.023 ± 0.001 c	0.812 ± 0.010 b
	SSG3	0.248 ± 0.003 a	0.112 ± 0.002 c	0.698 ± 0.002 a	0.046 ± 0.001 a	0.556 ± 0.006 c
Fe	SSG1	32.238 ± 0.024 c	38.533 ± 0.045 c	43.743 ± 0.092 c	17.710 ± 0.087 b	32.572 ± 0.009 b
	SSG2	39.016 ± 0.057 b	57.769 ± 0.062 a	61.272 ± 0.015 b	17.596 ± 0.069 b	54.834 ± 0.027 a
	SSG3	56.37 ± 0.032 a	52.648 ± 0.059 b	72.681 ± 0.088 a	22.715 ± 0.04 a	20.090 ± 0.016 c
Mn	SSG1	1.654 ± 0.010 c	6.008 ± 0.052 b	8.356 ± 0.039 c	3.785 ± 0.036 b	5.417 ± 0.033 b
	SSG2	2.541 ± 0.008 a	9.578 ± 0.069 a	9.436 ± 0.087 b	3.398 ± 0.013 c	6.918 ± 0.056 a
	SSG3	2.518 ± 0.010 b	5.771 ± 0.040 c	9.979 ± 0.054 a	4.138 ± 0.018 a	3.347 ± 0.036 c
Cu	SSG1	0.552 ± 0.007 a	0.398 ± 0.002 b	1.097 ± 0.009 b	0.156 ± 0.001 a	2.457 ± 0.033 b
	SSG2	0.409 ± 0.006 b	0.485 ± 0.003 a	1.288 ± 0.012 a	0.125 ± 0.003 b	2.929 ± 0.032 a
	SSG3	0.409 ± 0.002 b	0.277 ± 0.005 c	1.281 ± 0.005 a	0.114 ± 0.003 c	2.238 ± 0.019 c
Mo	SSG1	0.030 ± 0.001 c	0.034 ± 0.001 c	0.050 ± 0.001 c	0.018 ± 0.001 b	0.034 ± 0.001 b
	SSG2	0.041 ± 0.001 b	0.047 ± 0.001 a	0.062 ± 0.001 b	0.016 ± 0.001 c	0.053 ± 0.001 a
	SSG3	0.044 ± 0.001 a	0.043 ± 0.001 b	0.071 ± 0.003 a	0.020 ± 0.001 a	0.015 ± 0.001 c

Conclusions and Discussion

Seed stems are the key factor affecting the quality of medicinal materials. Studies have shown that the content of lobetyolin was positively correlated with the grade of seedlings, but negatively correlated with the content of polysaccharides[7], and the content of cichoric acid in *Brauneria purpurea* treatment of secondary seedlings was the highest in flowers, leaves and stems[8]. Zhang *et al.*[9] found that the difference of seed stems affected the difference of plant morphology and yield during the growth and development of *Pinellia pedatisecta* Schott, so it is appropriate to choose first-class seed stems. Consistent with the research, different kinds of stems can affect the quality and quality of *F. thunbergii* Miq.[10].

Soil fertility provides nutrients for the growth and development of *F. thunbergii* Miq. After the introduction of *F. thunbergii* Miq. from different provenances, the detection of soil available elements at different growth stages is conducive to studying the law of fertilizer demand of *F. thunbergii* Miq., which can improve the ratio of output to input to thereby obtain higher economic and environmental benefits. Song *et al.*[11] pointed out that the yield of *F. thunbergii* Miq. was positively correlated with the K content in soil and the K accumulation in plants. In this study, the stem size of different provenances also affected the availability of soil elements. The availability of elements N, P and K in the soil of SSG3 from Ningbo, Zhejiang Province was significantly higher than that of groups SSG1 and SSG2.

In this study, only field experiments were designed, but there was no correlation analysis on the effects of different stems on the effective components of *F. thunbergii* Miq. Further quality analysis is needed to provide more reference for high-yielding and efficient cultivation of introduced *F. thunbergii* Miq.

To sum up, in the introduction process of *F. thunbergii* Miq. to Wanzhou, Chongqing, small stems of Pan'an and Ningbo provenances (SSG3, 121 – 160/kg) and middle stems of Nantong and Fengjie provenances (SSG2, 81 – 120/kg) showed higher soil availability.

References

[1] Chinese Pharmacopoeia Commission. Chinese pharmacopoeia[S]. Beijing: China Medical Science Press, 2020: 305 – 306. (in Chinese).

[2] YU T, LIAN XJ, SUN YL, *et al.* Quality analysis of *Fritillaria thunbergii* Miq. origin and exsitu introduction[J]. Journal of Chengdu University: Natural Science, 2018, 37(4): 370 – 372, 383. (in Chinese).

[3] DAI YD, DU HH, ZHOU N, *et al.* Effects of trace element fertilizers on production and quality of *Fritillaria thunbergii* Miq. [J]. West China Journal of Pharmaceutical Sciences, 2020, 35(4): 411 – 415. (in Chinese).

[4] The Ministry of Agriculture of the People's Republic of China. NY/T 890 – 2004 Agricultural Industry Standard of the People's Republic of China: Determination of available zinc, manganese, iron, copper in soil[S]. Beijing: China Standards Press, 2005. (in Chinese).

[5] TONG SH. Study on the correlation between the measured values of soil available trace elements and plant absorption[D]. Linfen: Shanxi Normal University, 2012. (in Chinese).

[6] BAO SD. Soil agrochemical analysis[M]. Beijing: China Agriculture Press, 2000. (in Chinese).

[7] WANG HZ, LIAN ZX, LU GD, *et al.* Relationship between seedling grade of *Codonopsis pilosula* and yield and quality of medicinal materials [J]. China Journal of Chinese Materia Medica, 2016, 41(21): 3950 – 3955. (in Chinese).

[8] LIU XY, ZHANG HM, SU SS, *et al.* Study on grading standard of *Echinacea purpurea* seedlings[J]. Journal of Chinese Medicinal Materials, 2016, 39(2): 258 – 261. (in Chinese).

[9] ZHANG G, MENG YJ, JIN XS, *et al.* Effects of seed stem type on yield and quality of medicinal plant *Pinellia pedatisecta* Schott[J]. Crops, 2017(2): 168 – 172. (in Chinese).

[10] CHEN YB. Comprehensive evaluation of planting density and stem size on the quality of different *Fritillaria thunbergii* Miq. [D]. Chongqing: Chongqing Three Gorges University, 2021. (in Chinese).

[11] SONG LQ. Effects of potassium application on yield and quality formation and potassium utilization efficiency of *Fritillaria thunbergii* Miq. [D]. Hangzhou: Zhejiang Chinese Medical University, 2019.

Editor: Yingzhi GUANG Proofreader: Xinxiu ZHU

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[11] KAMRAN MA, EQANI SAMAS, BIBI S, *et al.* Bioaccumulation of nickel by *E. sativa* and role of plant growth promoting rhizobacteria (PGPRs) under nickel stress[J]. Ecotoxicology and Environmental Safety, 2016(126): 256 – 263.

[12] URAGUCHI S, FUJIWARA T. Cadmium transport and tolerance in rice: Perspectives for reducing grain cadmium accumulation[J]. Rice, 2012, 5(1): 1 – 8.

[13] KHANAM R, KUMAR A, NAYAK A, *et al.* Metal (loid) s (As, Hg, Se, Pb and Cd) in paddy soil: Bioavailability and potential risk to human health[J]. Science of the Total Environment, 2019(699): 134330.

[14] LI RY, XU XH, XU ZD, *et al.* Total mercury and methylmercury concentrations and risk assessments in rice plants collected from a river watershed in a typical mercury mining area of Guizhou[J]. Research of Environmental Sciences, 2016, 29(12): 1829 – 1839.

[15] JIANG YJ, HU X F, SHU Y, *et al.* Accumulation of heavy metals in the soil-rice system and assessment of dietary safety of the rice produced in the paddy fields: A case study of a town in the northern part of Hunan Province[J]. Acta Pedologica Sinica, 2017, 54(2): 410 – 420.

[16] ZHENG HY, YAO XR, HOU YL, *et al.* Establishment of heavy metal bioaccumulation model of soil pattern-crop system in China[J]. Journal of Agro-Environment Science, 2015, 34(2): 257 – 265.

[17] ABBAS G, MURTAZA B, BIBI I, *et al.* Arsenic uptake, toxicity, detoxification, and speciation in plants: Physiological, biochemical, and molecular aspects[J]. International Journal of Environmental Research and Public Health, 2018, 15(1): 59.

Editor: Yingzhi GUANG Proofreader: Xinxiu ZHU