Rhizosphere Soil Quality Characteristics of Senescent versus Normally Growing Dingtan Prickly Ash in Central Guizhou Rocky Desertification Area: Postprint

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Abstract

To investigate the causes of senescence and degradation in *Zanthoxylum planispimum* var. *dintanensis* and achieve stable and sustainable stand management, senescent and degraded plants characterized by yellowing flowers and normally growing plants were selected as research subjects. Using soil agrochemical and environmental mineralogical methods, the mineral element contents in rhizosphere soils of different plants were analyzed and comprehensive soil quality was evaluated. The results showed: (1) Rhizosphere soils of normally growing plants exhibited significantly higher overall contents of C, P, K, S, Se, Sr, Mo, and oxides compared to senescent and degraded plants, while total nitrogen, available phosphorus, available nitrogen, Cu, Pb, Zn, and Cr showed no significant differences, and variation patterns of other elements were not evident. The available forms of elements also influenced plant growth. From the perspective of plant nutritional requirements, macro-, meso-, and micro-elements all exerted dominant effects on soil quality. (2) The rhizosphere soil quality index was highest for normally growing plants (3) and lowest for senescent and degraded plants (1), indicating that soil quality influences the senescence and degradation of *Zanthoxylum planispimum* var. *dintanensis*. (3) In the management of *Zanthoxylum planispimum* var. *dintanensis* stands, good soil structure should be cultivated, attention should be paid to the comprehensiveness and balance of soil nutrients, and deficiency effects caused by excessively low mineral element contents should be considered.

Full Text

Preamble

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Title: Soil Quality in the Root Zone of Aging/Degraded versus Normally Growing *Zanthoxylum planispimum* var. *dintanensis* in the Rocky Desertification Area of Central Guizhou

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Abstract

To investigate the causes of aging and degradation in *Zanthoxylum planispimum* var. *dintanensis* and to achieve stable and sustainable forest stand management, this study examined aging/degraded plants (characterized by yellow flowers) and normally growing plants. Using soil agrochemical and environmental mineralogical methods, we analyzed mineral element contents in the root-zone soil of different plants and evaluated comprehensive soil quality. The results showed that: (1) The root-zone soil of normally growing plants had significantly higher contents of C, P, K, S, Se, Sr, Mo, and oxides compared to aging/degraded plants, while total nitrogen, available phosphorus, available nitrogen, Cu, Pb, Zn, and Cr showed no significant differences, and other elements exhibited no clear patterns. Available element contents also affected plant growth. From the perspective of plant nutritional requirements, macro-, meso-, and micro-elements all exerted dominant effects on soil quality. (2) The root-zone soil quality index was highest for normally growing plant No. 3 and lowest for aging/degraded plant No. 1, indicating that soil quality influences the aging and degradation of *Zanthoxylum planispimum* var. *dintanensis*. (3) In managing *Zanthoxylum planispimum* var. *dintanensis* stands, it is essential to cultivate good soil structure, ensure comprehensive and balanced soil nutrients, and address deficiencies caused by excessively low mineral element contents.

Keywords: aging and degradation, *Zanthoxylum planispimum* var. *dintanensis*, root-zone soil quality, principal component analysis, rocky desertification area of central Guizhou

1.1 Study Area Overview

The study area is located in Cha' eryan Village, Beipanjiang Town, Zhenfeng County (105°38 48.48 E, 25°39 35.64 N), featuring distinct habitat uniqueness: (1) **Arid-hot climate**: The region has a subtropical humid monsoon climate with an average annual rainfall of 1,100 mm, unevenly distributed across seasons, with severe droughts in winter-spring and summer. The mean annual temperature is 18.4 °C, with average extreme maximum and minimum temperatures of 32.4 °C and 6.6 °C, respectively, and accumulated annual temperature of 6,542.9 °C. The area experiences warm-dry winters/springs and hot-humid summers, with abundant heat resources. (2) **Valley topography**: The region features deeply incised river valleys with deeply buried groundwater, elevations ranging from 370–1,473 m, and a vertical elevation difference of approximately 1,100 m, creating typical valley climate characteristics. (3) **Developed rocky desertification**: Located in the Beipan River basin, the forest coverage is less than 30%, bedrock exposure ranges from 50%–80%, carbonate rocks account for 78.45% of the area, and soils are primarily limestone-derived calcareous soils. The surface is fragmented, with most areas classified as moderate to severe rocky desertification.

1.2.1 Sample Collection

The criterion for identifying aging/degraded *Zanthoxylum planispimum* var. *dintanensis* was a yellow flower proportion exceeding 30%. In April 2017, sample plots were established in areas with consistent elevation, slope, slope position, and aspect, divided into two types: aging/degraded and normally growing. Each type was further categorized based on growth conditions, and 3–5 plants were selected for each category. Approximately 1 kg of root-zone soil (0–20 cm depth) was collected per plant (using actual depth where soil was less than 20 cm). Soil samples were mixed uniformly, plant roots, animal/plant residues, and gravel were removed, and samples were sealed in plastic bags and transported to the laboratory. Samples were air-dried in a ventilated, dark place, ground to pass through 2 mm and 0.15 mm sieves (95% of samples), and stored in glass bottles for analysis.

Table 1 Basic characteristics of tested plants

Note: SL1-SL3 are aging degraded plants 1-3, and ZC1-ZC3 are normal plants 1-3. The same below.

1.2.2 Sample Measurement

Soil organic carbon (SOC) was determined by the potassium dichromate external heating method, total nitrogen (TN) by the semi-micro Kjeldahl method, available nitrogen (AN) by the alkaline hydrolysis diffusion method, total phosphorus (TP) by perchloric acid-sulfuric acid digestion-molybdenum antimony colorimetry-UV spectrophotometry, available phosphorus (AP) by ammonium fluoride-hydrochloric acid extraction-molybdenum antimony colorimetry-UV spectrophotometry, total potassium (TK) by hydrofluoric acid digestion-flame photometry, and available potassium (AK) by neutral ammonium acetate extraction-flame photometry (Bao, 2008). Boron (B), arsenic (As), and selenium (Se) were determined according to the *Regional Geochemical*

Exploration Specification (DZ/T0167-2006). Silicon dioxide (SiO), calcium oxide (CaO), magnesium oxide (MgO), sodium oxide (Na O), aluminum oxide (Al O), iron(III) oxide (Fe O), copper (Cu), zinc (Zn), lead (Pb), chromium (Cr), cadmium (Cd), titanium (Ti), nickel (Ni), cobalt (Co), strontium (Sr), molybdenum (Mo), chlorine (Cl), and sulfur (S) were determined according to the *Multi-purpose Regional Geochemical Survey Specification (1:250,000)* (DZ/T0258-2014).

1.3 Data Processing and Analysis Methods

Experimental data were calculated and organized using Microsoft Excel 2010, plotted using OriginPro 8.5.1, and statistically analyzed using SPSS 21.0. One-way ANOVA was used to test differences in soil parameters between different plant types. Principal component analysis (PCA) was employed to extract comprehensive indicators reflecting multiple original metrics for soil quality evaluation. Significance levels were set at $P = 0.05$ and highly significant levels at $P = 0.01$.

This study used 29 soil factors including SOC, TN, and AN as basic indicators for evaluating root-zone soil quality of *Zanthoxylum planispimum* var. *dintanensis*. Due to inconsistent units and large numerical differences among these indicators, values were standardized before evaluation. PCA was used to extract major factors influencing soil quality and reduce dimensionality of multidimensional soil nutrient variables. Principal component communality, loading matrices, and contribution rates were obtained. Principal component eigenvectors were calculated as loading matrix values divided by the square root of the corresponding eigenvalue. Principal component scores for each type were obtained by multiplying eigenvectors with standardized data. The integrated fertility index (IFI) was calculated using the weighted method (Jin et al., 2008):

$$IFI = \sum W_i \times F_i$$

where W is the contribution rate of each principal component and F is the principal component score for each type.

2.1.1 Macroelements

Macroelements showed differences between aging/degraded and normally growing *Zanthoxylum planispimum* var. *dintanensis* plants (Figure 1 [Figure 1: see original paper]). SOC, TP, TK, and AK showed significant differences ($P < 0.05$), while TN, AN, and AP showed no significant differences ($P > 0.05$). This indicates that C, P, and K are mineral elements affecting the aging and degradation of *Zanthoxylum planispimum* var. *dintanensis*, and that available nutrients influence plant growth.

2.1.2 Oxides

Among the six oxides measured, Fe O , CaO, MgO, and Na O showed significant differences between aging/degraded and normally growing types, while Al O and SiO were mostly significantly different, with overall lower oxide contents in aging/degraded types. This suggests that oxide deficiency contributes to the aging and degradation of *Zanthoxylum planispimum* var. *dintanensis*, indicating that meso-, micro-, and beneficial elements also significantly affect plant growth and physiological traits.

Figure 2 [Figure 2: see original paper] Oxide content

2.1.3 Medium and Trace Mineral Elements

Among the measured meso- and trace elements (Table 2), S, Se, Sr, and Mo mostly showed significant differences between aging/degraded and normally growing types, with higher contents in normally growing plants. Cu, Pb, Zn, and Cr showed no significant differences, while other elements showed some variation but no clear patterns. These results also indicate that deficiencies in meso- and trace elements cause aging and degradation of *Zanthoxylum planispimum* var. *dintanensis*, with notable deficiency effects.

Table 2 Content of other mineral elements

2.2 Root Zone Soil Quality Evaluation

Based on the criteria of eigenvalue > 1 and cumulative contribution rate $> 85\%$, four principal components were extracted from the rotated results, with eigenvalues of 10.68, 6.77, 4.22, and 3.84, respectively. The cumulative contribution rate of these four components was 87.94%, indicating they reflected 87.94% of the total information provided by the original data (Table 3). According to the >85% cumulative contribution rate principle, these four principal components could explain the original variables, thus warranting further analysis of the first four principal components.

Table 3 Eigenvalue and contribution rate in principal components analysis

The factor loading matrix (Table 4) showed that the first principal component was significantly correlated with SOC, AN, Cd, S, and B, with large loading coefficients. The second principal component had large loadings on MgO and Na O. The third principal component was mainly dominated by Co. The fourth principal component' s main controlling indicator was AP (absolute factor loading values > 0.9). Different principal components represented different soil property information, comprehensively and intuitively expressing soil quality variation trends.

Table 4 Component matrices pre and post rotated

2.3 Soil Quality Index

As shown in Table 5 , the soil quality indices for different types ranked as ZC3 > SL2 > SL3 > ZC2 > ZC1 > SL1. Normally growing plant ZC1 and aging/degraded plant SL1 ranked 1st and 6th, respectively, but the ranking order changes were not obvious. The SL3 type had the highest score on the first principal component, ZC3 ranked highest on the second and fourth principal components, and ZC1 had the highest relative score on the third principal component, indicating that not all elements showed a "low inhibition, high promotion" effect on *Zanthoxylum planispimum* var. *dintanensis* growth.

Table 5 Factor scores and comprehensive evaluation of different types

3.1 Influence of Soil Mineral Elements on Aging and Degradation of *Zanthoxylum planispimum* var. *dintanensis*

Mineral elements directly affect crop yield and quality and play important roles in crop growth and physiological processes (Zhao et al., 2014). Different application rates and ratios also affect human health (Zhao et al., 2017), making the relationship between mineral elements and soil and plant nutrition a focus of scholarly attention. According to Tables 3 and 4, the first principal component had a large influence weight on soil quality (36.82%), with aging/degraded plants generally ranking higher, indicating that both macroelements and meso-/microelements simultaneously affect soil quality, and that the available quantity of nutrients may have a greater impact on plant growth. Therefore, extensive management focusing only on N, P, and K nutrient management should be abandoned. The second and third principal components were generally higher in normally growing plants, dominated by Mg, Na, and Co. Although karst areas are characterized by high Ca and Mg, soil Mg content also varies considerably and can become a limiting factor, possibly because soil quality degradation reduces the dissolution and release rates of elements from parent rock, suggesting that aging and degradation of *Zanthoxylum planispimum* var. *dintanensis* likely affects parent rock weathering. The fourth principal component showed no clear pattern between aging/degraded and normally growing types, possibly because *Zanthoxylum planispimum* var. *dintanensis* roots have weak P absorption capacity, making P's effect on plant growth insignificant. In summary, we hypothesize that deficiencies in mineral elements, especially meso- and trace elements and their available forms, cause aging and degradation of *Zanthoxylum planispimum* var. *dintanensis*, while aging/degraded plants also have reduced root nutrient absorption capacity, indicating that systematic and ecological theories should be applied to solve this problem.

Mg plays an important role in chlorophyll synthesis and photosynthesis, being a necessary structure for photon quanta and a prerequisite for effective photosynthetic carbon assimilation. Mg deficiency may reduce chlorophyll synthesis capacity in *Zanthoxylum planispimum* var. *dintanensis*. Na is an essential trace element for C4 photosynthetic pathway plants and is irreplaceable (Lu, 2003). Na deficiency may hinder photosynthesis, possibly causing the high proportion of yellow leaves in *Zanthoxylum planispimum* var. *dintanensis*, and may also lead to lower cellular osmotic pressure, weakened turgor maintenance, and affected nutrient transport and translocation within plants. Co functions to stabilize lipoprotein complexes on chloroplast membranes (Lu, 2003), and adequate Co content can promote photosynthesis and increase fruit yield. In this study, aging/degraded *Zanthoxylum planispimum* var. *dintanensis* plants showed increasing yellow leaves starting from branch tips, possibly related to reduced photosynthetic capacity caused by element deficiencies or affected element transport dynamics. Appropriately increasing soil Co content can increase chloroplast number, surface area, and pigment content on leaf areas, promote photosynthesis, and inhibit plant aging and degradation. The above analysis indicates that mineral element deficiencies affect plant growth and physiological traits, reduce photosynthetic capacity, affect element absorption, transport, and transformation, and consequently affect plant growth and even lifespan.

3.2 Application of Principal Component Analysis in Soil Quality Evaluation

Soil quality is a comprehensive manifestation of soil structure, properties, and functions that can sensitively indicate dynamic changes in soil conditions. Soil quality evaluation provides a comprehensive assessment of soil productivity, helps diagnose causes of soil degradation, and integrates soil health management strategies. China has conducted much meaningful work on soil quality evaluation indicator systems and methods, but unified standards and fixed methods are still lacking (Lü et al., 2017). Currently, principal component analysis is widely used for quantitative soil quality evaluation (Cheng et al., 2018), transforming multiple indicators through linear transformation into a few independent principal components that fully characterize overall information, minimizing data redundancy (Zhang, 2006). This study used PCA to evaluate root-zone soil quality of *Zanthoxylum planispimum* var. *dintanensis* under different growth conditions. The extracted principal components reflected over 85% of the information from all indicators, and soil quality showed some correlation with aging degree, providing theoretical and practical value for guiding sustainable land resource utilization. Therefore, PCA results can basically reflect root-zone soil quality of different plants objectively, helping propose efficient nutrient management strategies based on evaluation results. The dominant factors screened by PCA in this study included SOC, available nutrients, and essential beneficial trace elements, indicating that comprehensive and balanced nutrient management should be emphasized in sustainable management of *Zanthoxylum planispimum* var. *dintanensis*. The extracted information was relatively complete, enabling establishment of a simplified soil fertility quality evaluation indicator system that truly reflects soil quality while greatly reducing evaluation workload.

3.3 Sustainable Management Strategies for *Zanthoxylum planispimum* var. *dintanensis* Based on Mineral Elements

Aging and degradation of *Zanthoxylum planispimum* var. *dintanensis* has affected the consolidation of rocky desertification control achievements, reduced farmers' enthusiasm for planting this species in Guizhou' s karst mountainous areas, and is detrimental to sustainable ecological and economic development in mountainous regions. Urgent scientific and technological measures are needed to achieve healthy management of *Zanthoxylum planispimum* var. *dintanensis*. This study' s results indicate that low contents of mineral elements such as Mg, Na, and Co may be key factors affecting normal growth and physiological status of *Zanthoxylum planispimum* var. *dintanensis*, thereby limiting photosynthetic capacity and material synthesis and accelerating aging and degradation. This suggests that supplementing mineral elements and creating good soil structure are important pathways to improve *Zanthoxylum planispimum* var. *dintanensis* productivity. Based on the principle that structure determines function, good soil structure is necessary for optimal soil function. This study shows that SOC is one of the main factors affecting soil quality, indicating that cultivating good soil aggregate structure is an important measure to improve *Zanthoxylum planispimum* var. *dintanensis* productivity. Although mineral elements are abundant in the geological environment, soils still show deficiency states, possibly due to low nutrient dissolution and release rates or because soil quality degradation, particularly reduced soil biological diversity and quantity, limits nutrient availability. Therefore, coordinating plant-soil relationships is key to *Zanthoxylum planispimum* var. *dintanensis* forest management. In recent years, aging and degradation of *Zanthoxylum planispimum* var. *dintanensis* has intensified, accompanied by increasingly extensive nutrient and water management, creating a vicious cycle that leads to 逐年降低的产量和品质. Therefore, water-nutrient coupling and self-sufficiency should become key measures for sustainable management of *Zanthoxylum planispimum* var. *dintanensis*, significantly influencing nutrient use efficiency.

In this study, since no publicly available soil quality evaluation indicator system including all plant nutrient elements has been released, whether some elements exhibit pollution effects or deficiency effects in plant growth and physiological processes remains uncertain, limiting in-depth evaluation of results. Moreover, current soil quality research generally assumes that higher mineral element content is better (upper-limit function), but element concentrations exceeding certain ranges can show inhibitory or antagonistic effects. Combined with differences in plant tolerance capacity and comprehensive effects of element interactions, this creates difficulties in quality evaluation and cause diagnosis. Therefore, the mineral element mechanism affecting aging and degradation of *Zanthoxylum planispimum* var. *dintanensis* requires further research.

4 Conclusions

(1) Deficiencies in C, P, K, S, Se, Sr, Mo, and oxides are among the causes of aging and degradation of *Zanthoxylum planispimum* var. *dintanensis*, and available element contents also affect plant growth. (2) The soil quality index ranking of ZC3 > SL2 > SL3 > ZC2 > ZC1 > SL1 indicates that comprehensive soil quality has some influence on aging and degradation of *Zanthoxylum planispimum* var. *dintanensis*. (3) In managing *Zanthoxylum planispimum* var. *dintanensis* forest land, good soil structure should be cultivated and comprehensive, balanced nutrient management should be emphasized.

References

ABER JD, MAGILL A, MCNUITY SG, et al, 1995. Forest biogeochemistry and primary production altered by nitrogen saturation[J]. Water Air Soil Poll, 85(3):1665-1670.

BAO SD, 2008. Analysis of soil agrochemical [M]. 3rd ed. Beijing: China Agriculture Press. [鲍士旦, 2008. 土壤农化分析 (第三版)[M]. 北京: 中国农业出版社.]

CHEN FZ, 2015. Effects of application and ratio of nitrogen, phosphorus, and potassium on mineral nutrient absorption and yield of cucumber[J]. J NW A & F Univ, 43(6): 174-180. [陈凤真, 2015. 氮磷钾用量及配比对黄瓜矿质元素吸收和产量的影响 [J]. 西北农林科技大学学报, 43(6): 174-180.]

CHEN MJ, DUAN ZQ, LIN XG, et al, 2011. Status quo and prospects of the study on soil quality stands in China[J]. Acta Pedol Sin, 48(5): 1059-1071. [陈美军, 段增强, 林先贵, 2011. 中国土壤质量标准研究现状及展望 [J]. 土壤学报, 48(5): 1059-1071.]

CHENG C, WANG JJ, CHENG HH, et al, 2018. Effects of straw returning and tillage system on crop yield and soil fertility quality in paddy field under Double-Cropping-Rice System[J]. Acta Pedol Sin, 55(1): 247-257. [成臣, 汪建军, 程慧煌, 等, 2018. 秸秆还田与耕作方式对双季稻产量及土壤肥力质量的影响 [J]. 土壤学报, 55(1): 247-257.]

DING XC, 2006. Effect of mineral components on promotion of *phyllostachys praecox* flowering in the mulching cultivation stands[J]. J Zhejiang For Sci & Technol, 26(4): 10-14. [丁兴萃, 2006. 矿质元素在保护地栽培促进早竹开花中的影响 [J]. 浙江林业科技, 26(4):10-14.]

GILLIAM FS, DICK DA, 2010. Spatial heterogeneity of soil nutrients and plant species in herb-dominated communities of contrasting land use[J]. Plant Ecol, 29(1): 83-94.

GUSEWELL S, 2005. Responses of wetland graminoids to the relative supply of nitrogen phosphorus[J]. Plant Ecol, 176(1): 35-55.

JIN ZZ, LEI JQ, XU XW, et al, 2008. Evaluation of soil fertility of the shelter-forest land along the Tarim Desert Highway[J]. Chin Sci Bull, 53(S2): 125-136.

JOIMEL S, CORTET J, JOLIVET CC, et al, 2016. Physico-chemical characteristics of topsoil for constrasted forest, agricultural, urban and industrial land uses in France[J]. Sci Total Environ, 545-546: 40-47.

LI XM, MA LJ, BU N, et al, 2017. Endophytic infection modifies organic acid and mineral element accumulation by rice under Na CO stress[J]. Plant & Soil, 420: 93-103.

LU JL, 2003. Plant Nutrition (Second Edition)[M]. Beijing: China Agr Univ Press. [陆景陵, 2003. 植物营养学 (第 2 版)[M]. 北京: 中国农业大学出版社.]

LÜ ZZ, WU XD, HOU HQ, et al, 2017. Effect of different application ratios of chemical and organic fertilizers on soil quality in double cropping paddy fields[J]. J Plant Nutr Fert, 23(4): 904-913. [吕真真, 吴向东, 侯红乾, 等, 2017. 有机—无机肥配施比例对双季稻田土壤质量的影响 [J]. 植物营养与肥料学报, 23(4): 904-913.]

MAO QG, LU XK, CHEN H, et al, 2015. Responses of terrestrial plant diversity to elevated mineral element inputs[J]. Acta Pedol Sin, 35(17): 5884-5897. [毛庆功, 鲁显楷, 陈浩, 等, 2015. 陆地生态系统植物多样性对矿质元素输入的响应 [J]. 生态学报, 35(17): 5884-5897.]

WANG YY, SUN J, LIU ZH, et al, 2016. Soil fertility quality assessment of *Magnolia officinalis* communities in Qinba mountains[J]. Acta Ecol Sin, 36(16), 5133-5141. [王钰莹, 孙娇, 刘政鸿, 等, 2016. 陕南秦巴山区厚朴群落土壤肥力特征 [J]. 生态学报, 36(16): 5133-5141.]

WHYTEMARE AB, EDMONDS RL, ABER JD, et al, 1997. Influence of excess nitrogen deposition on a white spruce (*Picea glauca*) stand in southern Alaska[J]. Biogeochemistry, 38(2): 173-187.

ZHANG L, WEN SL, CAI ZJ, et al, 2014. Characteristics of soil fertility under different vegetation types in the hilly red soil region of southern Hunan[J]. Acta Ecol Sin, 34(14): 3996-4005. [张璐, 文石林, 蔡泽江, 等, 2014. 湘南红壤丘陵区不同植被类型下土壤肥力特征 [J]. 生态学报, 34(14): 3996-4005.]

ZHANG PP, PU XZ, ZHANG WF, 2018. Soil quality assessment under different cropping system and straw management in farmland of arid oasis region[J]. Chin J Appl Ecol, 29(3): 839-849. [张鹏鹏, 濮晓珍, 张旺锋, 2018. 干旱区绿洲农田不同种植模式和秸秆管理下土壤质量评价 [J]. 应用生态学报, 29(3): 839-849.]

ZHANG RC, 2006. Multivariate statistical analysis[M]. Beijing: Sci Press: 165-183. [张润楚, 2006. 多元统计分析 [M]. 北京: 科学出版社: 165-183.]

ZHAO QH, SUN LT, WANG Y, et al, 2014. Effects of arbuscular mycorrhizal fungi and nitrogen regimes on plant growth, nutrient uptake and tea quality in *Camellia sinensis* (L.) O. Kuntze[J]. Plant Physiol J, 50(2): 164-170. [赵青华, 孙立涛, 王玉, 等, 2014. 丛枝植菌根真菌和施氮量对茶树生长、矿质元素吸收与茶叶品质的影响 [J]. 植物生理学报, 50(2): 164-170.]

ZHAO Y, FENG YN, LI L, et al, 2017. Tissue-specific regulation of the contents and correlations of mineral elements in hens by zinc oxide nanoparticles[J]. Biol Tra Elem Res, 177: 353-366.

ZHU NN, HAN S, YANG CN, et al, 2016. Element-tracing of mineral matters in *Dendrobium officinale* using ICP-MS and multivariate analysis[J]. Spinger Plus, 5: 979.

Note: Figure translations are in progress. See original paper for figures.