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Review

Environmental factors affecting growth and development of Banlangen *(Radix Isatidis)* in China

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Banlangen (*Radix Isatidis*) is an herbal medicine, and grows in various parts of China. It can be classified into North *Radix Isatidis* and South *Radix Isatidis*. With the rising demand of users all over the world, more and more popularly used herbal plants are now grown in agricultural fields. The natural force of supply and demand has encouraged the cultivation of Banlangen in China. However, the cultivation of Banlangen at a large scale does not always result in high yield and good quality, because many agronomic factors have an influence on the growth of Banlangen, such as variety, soil properties, climate and other environmental factors. This paper provides a brief review on the progresses of recent research regarding agronomic factors that affect the growth and quality of Banlangen in China and elsewhere.

Key words: Banlangen *(Radix Isatidis)*, agronomic factors, growth, quality.

INTRODUCTION

Nature of Chinese material is the nucleus in the theory of Chinese material medicine based on the recognition of traditional Chinese medicine, which is the character of the drug related to curative effect (Gao, 2012). Banlangen (*Radix Isatidis*) is an official herbal medicine with the part of anti-virus, anti-endotoxin, anti-inflammatory and improve immune system and grows in various parts of China (Chen et al., 2011; Du et al., 2013; Li and Yang, 2014). Studies have shown that the drawing material of *R. Isatidis* had a strong effect as antiviral, and which is often used in preventing virus or bacterial infection in clinical practice, and therefore, the *R. Isatidis* is considered to prevent diseases of pestilent maculae, fever headache, swollen-head infection, scarlet fever, pharyngitis, chicken pox, measles,hepatitis and flu (Huang, 2009; Guo et al., 2011; Xiao et al., 2014; Chen et al., 2015).

R. Isatidis can be classified into North *R. Isatidis* and South *R. Isatidis*. North *R. Isatidies* is the root of *Isatis indigotica* Fortune which belongs to Cruciferae family.

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South *R. Isatidies* is the root of *Strobilanthes cusia* (Ness) Bremek which belong to the Acathaceae family (Lou and Qin, 1995). Because of the differences between them in origin, trait, chemical composition, function and indications, it is common to distinguish between them in clinical application. Formation of Chinese material medical nature shows that the herbal plants receives the change of physical environmental factors, and resulted from the synthesis of the factors, including climate, soil, biology, and topography (Tang et al., 2010). Like other crops, growth and development of medicinal plants are affected by environmental factors (Yang and Tian, 2004). Previous studies showed that biological environment would have effect on plant morphology, especially blade size, texture, thickness and plant morphology (Huang et al., 2009).

CLIMATIC FACTORS

Climatic factors include light, temperature, moisture, and so on (Yang and Tian, 2004). They determine the processes of soil water and heat conditions, and are the primary factors for the development of Chinese herbal medicine (Yang et al., 2001). There are different requirements for environmental conditions between different varieties; wild species and cultivars from germination to its growth stage of *R. Isatidis*. Temperature and moisture are two important factors for the germination of *I. indigotica* seeds, and 30°C is the optimum germination temperature (Bai et al., 2009; Dong et al., 2006). The optimal growth temperature for *I. indigotica* fort is 18 - 23°C during the day and 13 -18°C at night and the optimal humidity is 80 - 90% (Ma and Lian, 2005). But appropriate low temperature stress will increase content of indirubin (Duan, 2006). *Baphicacanthus cusia* (Nees) is mainly distributed in Jiangsu, Zhejiang, Fujian, Taiwan, Guangdong, Guangxi, Guizhou and Yunnan of China. It also likes sunshine and warm temperature. *B. cusia* (Nees) grows well at temperature of 15 - 30°C and humidity of 70% or more (Du, 2008). Different condition of slight temperature and humidity may result in difference in yield and quality of *R. Isatidis* (Yang et al., 2001).

Light is one of the most important environmental factors that affect plant survival, growth, reproduction and distribution of *R. Isatidis*, although, it had no significant effects on seed germination (Bai et al., 2009) and adequate illumination time is conducive to increase plant height, number of branches, dry matter weight and indirubin content (Du, 2008). Adequate illumination can improve the yield and quality of *B. cusia* (Nees); light intensity affects photosynthesis and different plant species respond differently to light intensity (Anjana and Pramod, 2010). The strength of illumination will bring different actions on the growth and development of traditional Chinese medicine for different varieties (Yang et al., 2001). Under given environmental conditions, net photosynthetic rate (Pn) and water use efficiency of *R. Isatidis* leaves increased with photosynthetically active radiation (PAR), but when the PAR reaches certain threshold, the net photosynthetic rate and water use efficiency decline (Zhang et al., 2004), which may be caused by excess light photoinhibition (Powles, 1984).

SOIL FACTORS

Soil factors include soil texture, physical and chemical properties, field holding capacity, nutrient and so on (Yang et al., 2004). *R. Isatidis* plants generally have no strict soil requirements, with soil pH from slightly acidic to slightly alkaline. However, it is conducive to growth of *R. Isatidis* in loose and fertile sandy loam or light sandy, with soil temperature around 18°C and soil moisture at 60 - 80% (Ma et al., 2005). For *B. cusia* (Nees), in the optimal soil conditions are acidic or neutral sandy soil or loam, soil moisture at 22 - 33% (Du, 2008). If *R. Isatidis* plants are subjected to severe water stress (the lack of soil water or too much), their growth and development will be negatively affected. Studies showed that the water demand critical period of *Isatis tinctoria* L. is in July when accumulation of the indirubin decreased with increasing degree and length of drought stress (Tan et al., 2008); water stress also reduced root activity and biomass production. However, water use efficiency increased (He, 2008). Studies also showed that with the increasing of drought stress, chlorophyll content, photosynthesis, transpiration rate and biomass yield were reduced. Adequate yield and quality of *I. tinctoria* L. were obtained when soil moisture was maintained at 60 - 80% of field holding capacity (Ma et al., 2005; Tan et al., 2008). Root growth is closely related to soil moisture; excessive soil moisture is conducive to the growth of stems and leaves, but reduces the accumulation of the root dry matter (Zhang and Ke, 2010). Meanwhile, alcohol dehydrogenase activity of the roots was induced under excessive soil moisture, which helps alleviate the damage to *R. Isatidis* (Tang et al., 2011).

Soil nutrients and fertilizers

These play a very important role in the formation of yield and quality of herbal plants. The content of the epigoitrin in *R. Isatidis* plants was negatively correlated with total and nitrate nitrogen while the contents of the uridine and adenosine were negatively correlated with soil available potassium and affected by soil pH and total P (Pan and Liu, 2001; Chu et al., 2007).

Though no systematic studies were conducted on fertilization effects on *R. Isatidis*, the importance of fertilization for the yield and quality of medicinal plants has been increasingly recognized. Studies have shown that nitrogen fertilizer is beneficial to improve the yield of *R. Isatidis*, organic manure and chemical fertilizer combination is more advantageous to improve the yield of *R. Isatidis* (Qin et al., 2015). Appropriate amounts of phosphorus and organic fertilizers were reported to reduce arsenic accumulation in *R. Isatidis* (Gao, 2012). Application of nitrogen (N) and phosphorus (P) together improved soluble protein content of *I. indigotica* fort, but single N application reduced the root to shoot ratio while single P fertilizer increased the root to shoot ratio. Iron, manganese and zinc play a catalytic role in the synthesis of indigo in *I. indigotica* fort leaves and Isatis root (Wu, 2008). The concentrations of N, K and P in *B. Cusia* Bremek plants varied with organs and growth periods: decreasing in the order of leaves > stems > roots. The content of N is highest in 7- 8 months after germination, P is highest in June and July and K is highest in August. *B. Cusia* Bremek plants have four major nutrition periods: planting and sprouting, young shoot, vigorous growth and harvest period (Wei et al.,, 2004).

Combinations of different NPK formulation have a significant effect on the yield and polysaccharide content in *I. indigotica* (Wang et al., 2007). They also influence plant height, leaf number, leaf size, root weight, leaf weight, chlorophyll, soluble protein and soluble sugar content (Zhang and Ke, 2010). In order to harvest more leaves and roots, the optimal ratio of N:P is 1.99:1.91 (Wu, 2008). A combination of organic and mineral fertilizers was reported to improve the yield and quality of banlangen. An optimal proportion of N: P_2O_5: K_2O: organic fertilizer was found to be 1:0.68:0.90:0.82. This combination may vary with field conditions and herbal variety. In other experiments of *I. indigtica* fort, the optimal NPK application ratio was reported to be 2.5:1:4 (Ma and Lian, 2005), the different ratio may be caused by different varieties, but there is a common trend, that is, there are more demand for nitrogen and potassium than for P. The ratio of nitrogenous-phosphatic fertilizer was considered to be important for the prevention and cure of some diseases (Wei and Han, 2006).

Trace elements also play an important role in the yield and quality of *R. Isatidis*. Studies showed that during the vegetative growth spraying of Zn and Fe could promote chlorophyll synthesis of *I. indigtica* Fort. Spraying Fe, Mn and Zn promoted indigo synthesis in the leaves and roots (Wu, 2008). Copper inhibits indigo synthesis in the leaves and roost (Wu, 2008); spraying Fe and Mn improved the accumulation of indirubin in the leaves and roots, but Zn and Cu application is the opposite (Wu, 2008). Spraying ferrous sulfate, zinc sulfate and borax was reported to improve root diameter and root production of *I. indigtica* fort, whereas spraying ferrous sulfate, zinc sulfate improved the yield of leaves (He, 2008). The forms of nutrients also affect physiological characteristics, yield and quality of herbal plants (Tian et al., 1999; Ma et al., 2003; Li et al, 2007). For *I. indigotica*, increasing NH_4-N proportion was conducive to the accumulation of indirubin in the leaves and the polysaccharide in the root, while the accumulation of phosphorus, P, K and Mg was enhanced if NO_3^-N proportion was higher than NH_4^-N (Yan et al., 2010).

Soil heavy metals

Control of heavy metals is important for the quality of medicinal plants. Poisonings associated with the presence of heavy metals in some herbs were reported in Asia, Europe and the United States (Dunbabin et al., 1992; Markowitz et al., 1994; Olujohungbe et al., 1994). These heavy metals were mainly from the soil, water, or air (Mclaughlin, 1999; Caldas et al., 2004). Pollution of cadmium in soil is multi-faceted. It not only changed soil biological properties, such as microbial and enzyme activities, but also reduced nutrient cycling and soil fertility (Xia, 1997). Studies showed that high levels of Cadmium (Cd) reduced soil ammonification rate, with severe Cd pollution, microbial functional diversity and various enzyme activities that involve N and S cycle in the soil were significantly reduced (Kandeler et al., 1997). The activities of SOD and POD in *R. Isatidis* were also reported to decrease by soil Pb pollution (Meng et al., 2012), indicating that reactive oxygen radicals are produced beyond the plant's ability to scavenge. With increasing Cd concentration in soil, cumulative amount of Cd in *R. Isatidis* increased, and plant height, number of branches, number of leaves and other biomass indicators declined, and N, P, K content in the plants also decreased (Zhang et al., 2011). The content of indirubin, a major medicinal ingredient also decreased. Cadmium accumulated mainly in the roots, seldom delivered to above ground parts (He, 2007). Low concentrations of Cd (<5mg L^{-1}) may stimulate germination rate, germination index, and germination potential of *R. Isatidis* (Fu, 2007).

BIOLOGICAL FACTORS

Biological factors include planting density, weeds, diseases and pests, soil microbes and so on (Yang and Tian, 2004).

Sowing time

Sowing time should be also regarded as a biological factor, as it has a significant effect on contents of some chemical ingredients in the medicinal plants (Jiang et al., 2008; Qi et al, 2008; Wang et al., 2005). Studies have shown that chemical ingredients of European Isatis tended to decrease when sowing time was delayed (Sales et

Table 1. Environmental factors of affecting growth and development of Banlangen *(Radix Isatidis)*.

Environmental factors		Growth indicators	Active ingredient	References
Climatic	Light	plant height, number of branches	indirubin	Du (2008)
	Temperature		indirubin	Duan (2006)
	Moisture	root dry matter	Alcohol dehydrogenase	Zhang et al. (2010), Tang et al. (2011)
Soil	pH		Adenosine	Pan et al. (2001)
	Fieldholding capacity	root and biomass production, alcohol dehydrogenase	Indirubin	He (2008), Tan et al. (2008), Tang et al. (2011)
	nutrients	Epigoitrin, yield, chlorophyll soluble protein, and sugar	Adenosine Polysaccharide Indigo	Pan et al. (2001), Chu et al. (2007), Qin et al. (2015), Wang et al. (2007), Zhang et al. (2010), Du (2008)
	heavy metals	SOD and POD, oxygen radicals, biomass, germination index	Indirubin	Meng et al. (2012), He (2007), Zhang et al. (2011), Fu (2007)
Biological	Sowing time	Vegetative stage	Chemical ingredients	Chen et al. (2009), Sales et al. (2006)
	Density of planting	Plant growth		Chen (2011)

al., 2006). With the sowing time constantly delayed, soil temperature increased, the vegetative stage of *I. indigotic* Fort was shortened. As a result, the time for plants to expose light is insufficient and ultimately led to declining of active ingredient content in the plants (Chen et al., 2009). Sowing time varies with geographical location. Studies showed that the optimal sowing time was from April 15 to 25 in Yutian county of Hebei province (Ke et al., 2005).

Density of planting

Like other medicinal plants, appropriate density of planting is important for *R. Isatidis.* It affects the growth of leaves and roots, and yield. 25 cm × 7 cm is generally considered as an optimum planting density (Chen et al., 2009). Different variety of *R. Isatidis* requires different density of planting. The optimal space of *R. Isatidis* plants was 10 - 20 cm between plants, and 30 cm between rows (Ke et al., 2005). For *B. cusia* (Nees) Bremek, wide line spacing and narrow plant spacing can ensure the effective number of trees per unit area and promote plant growth. Therefore, it's appropriate planting density is 20 cm × 45 cm (Chen, 2011). Planting *B. cusia* (Nees) Bremek between banana forest or mandarin trees was reported to improve biological yield and adenosine content (Lin, 2011). The mechanisms are not fully understood. Inter-cropping with trees may provide more scattered light, which is beneficial to the growth of the herbal plants. Good management practices are also important for the growth of *B. cusia* (Nees) Bremek. For instance, pruning or multiple cuttings can effectively improve the production of the herbs (Chen, 2011).

CONCLUSIONS

With rising demand for herbal medicine worldwide, particularly in Asia, wild source of herbal plants is rapidly depleted. *R. Isatidis*, one of the most extensively used herbal medicines, has been increasingly grown in agricultural fields in the last two decades. Many factors are involved in the formation of active components in *R. Isatidis*. They include cultivars of *R. Isatidis*, climate conditions, soil fertility, and management practices. Light texture soil with pH near neutral is favorable to the growth of *R. Isatidis*. Combination of organic and inorganic fertilizers with balanced macro- and micronutrients enhances the yield and quality of this herbal plant, thus, it can be seen that environmental factors affect the growth and quality of *R. Isatidis* from different aspects, as is shown in Table 1. Further studies are needed to develop best management practices to warrant profitable production of herbal plants like *R. Isatidis* in agriculture and a more thorough and comprehensive research should be further expanded on important environmental factors and how to affect the growth and development of *R.*

Isatidis.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Anjana D, Pramod KJ (2010). Effects of different light levels on the growth traits and yield of centella asiatica. Middle-East J. Sci. Res. 5(4):226-230.

Bai LD, Dong XH, Sha STNYZ, Guo YH (2009). Studies on water absorption characteristics and the germination conditions of *Isatis indigotica* seeds. Guihaia, 29(6):836-838.

Caldas ED, Machado LL (2004). Cadmium, mercury and lead in medicinal herbs in Brazil. Food Chem. Toxicol. 42(4):599-603.

Chen K, Dou Y, Chen Z, Tian JZ (2011). Advance of Radix Isatidis Pharmacological Action and Active Substances. Chin. J. Exp. Trad. Med. Formulae, 17(8):275-278.

Chen SZ, Li JF, Zeng QM, Wu YH (2015). Study on Methods of Biological Assessment of antiviral activity of *Radix Isatidis* extract. Trad. Chin. Drug Res. Clin. Pharmacol. 26(2):198-201.

Chen XQ (2011). Study on key cultivation technologies of Baphicacanthus cusia (Nees) Bremek. Guangzhou University of Chinese Medicine: Master's degree thesis.

Chen YH, Tian HQ, Guo QS, Deng QH (2009). Effect of various planting densities on dynamic growth rhythm and root yield of Isatis indigotica. Conference Proceedings of the Tenth National Chinese medicine and natural medicine.

Chu BH, Mao SG, Ding XY (2007). The relationship between Alisma active ingredient and ecological factors. J. Nanjing Normal Univ. 30(2):98-103.

Duan (2006). Effects Of stress on effective components and stress-tolerant of gene of *Radix Isatidis*. Shaanxi normal university: Master's degree thesis.

Dong JZ, Liang S, Qin W (2006). Active ingredient content difference on roots, leaves of Isatis indigotica (Radix, Daqingye) from different regions. J. Appl. Ecol. 17(9):1613.

Du, P. X. A reseach on biological characteristics of Baphicacanthus cusia. 2008. Guangzhou University of Traditional Chinese Medicine: Master's degree thesis.

Du ZJ, Liu H, Zhang ZL, Li P (2013). Antioxidant and anti-inflammatory activities of Radix Isatidis Polysaccharide in murine alveolar macrophages. Int. J. Biol. Macromol. 58:329-335.

Dunbabin DW, Tallis GA, Popplewell PY (1992). Lead poisoning from Indian herbal medicine. Med. J. Aust. 157:835-836.

Fu SJ (2007). Impacts of *Radix Isatidis* of growth, quality under cadmium, lead contamination and control. Nanjing Agricultural University: Master's degree thesis.

Gao DN (2012). Effect of exogenous phosphorus or organic matter on absorption and transhipment of arsenic in *Radix Isatidis.* Hebei Agricultural University: master's degree thesis.

Guo HF, Mao JJ, Qian XF, Sun C, Sun HL (2011). Varicella-Zoster Virus Prophylaxis with the Traditional Chinese Medicine Radix Isatidis (Banlangen) in Patients with Multiple Myeloma Treated with Bortezomib, J. Altern. Complement. Med. 17(11):985-986.

He MH (2007). Effect of Cadmium on main medicinal components of Radix Isatidis and controlled techniques. Guizhou University, a master's degree thesis.

He YJ (2008). Research on standardized cultivation technology of Isatis tinctoria. Northwest Agriculture and Forestry University of Science and Technology: Master's degree thesis.

Huang JT (2009). Review on Chemical Constituents and Pharmacological Action of *Radix Isatidis*. Chin. J. Mod. Drug Appl. 3(15):197-198.

Huang YZ, Pan DR, Wang ZC, Ning WJ, Zhou YF (2009). Effects of different growing period on Baphicacanthus cusia (Nees) bremek medicine constituents. Chin. Agric. Sci. Bull. 25(16):75-78.

Jiang YS, Qi XX, Wei JQ (2008). Effect of sowing period on artemisia annual growth, yield and green artemisinin content. Seeds, 27(10):14. metals on the functional diversity of soil microbial communities. Biol. Fertil. Soils, 23(3):299-306.

Ke SY, Liu DL, Ma ZD, Liu QH (2005). Optimal experiments on the field cultivation of Chinese *Isatis Indigotica* Fort. J. Hebei Agric. Sci. 9(1):1-3.

Li WM, Shi JL, Han HS (2007). Effects of water saving irrigation Schedule on water consumption and yield of Indigowoad root. J. Irrigat. Drainage 26(6):106-109.

Li L, Yang ZF (2014). Review of the research mentalily on Radix Isatidis against multiple targets of influenza. J. N. Chin. Med. 46(3):203-204.

Lin XN (2011). Cultivation Research of Baphicacanthus Cusia Bremek Intercropping in Orchard.Guangzhou University of Chinese Medicine: Master's degree thesis.

Lou ZQ, Qin P (1995). Species collation and Quanlity study on common traditional Chinese medicine. Beijing: the Publishing House of Beijing Medical University and Chinese Peking Union Medical College. pp. 303-306.

Ma GS, Lian H (2005). The biological characteristics and the high yield cultivation techniques of *Isatis indigotica* Fort. Chin. Agric. Sci. Bull. 21:10.

Ma X.H, Wang XC, Wang ZQ (2003). Effect of N-form on photosynthetic characteristics in late growth stages and spikes of wheat cultivars with specialized end-uses. Acta Ecologica Sinica, 23(12):2587-2593.

Markowitz SB, Nenez CM, Klitzman S (1994). Lead poisoning due to haige fen: the porphyry content of individual erythrocytes. J. Am. Med. Assoc. 271:932-934.

McLaughlin MJ, Parker DR, Clark JM (1999). Metals and micronutrients—food safety issues. Field Crops Res. 60:143-163.

Meng HM, Jin CY, Zhang FQ (2012). The Effect of Ca^{2+} on *Radix Isatidis* seedling physiological characteristics under Pb^{2+} stress. Crops, 1:84-87.

Olujohungbe A, Fields PA, Sandford AF (1994). Heavy metal intoxication from homeopathic and herbal remedies. Postgrad. Med. J. 70:764-769.

Pan KW, Liu ZZ (2001). Applications of grey correlation and cluster analysis on the artificial community environment relationship of cercidiphyllum. J. Appl. Ecol. 12(2):161-167.

Powles CB (1984). Photoinhibition induced by visible light. Annu. Rev. Plant Physiol. 35(4):15-44.

Qi D, Zhang YL, Sun H (2008). Effect of different sowing period on yield and quality of achyranthes bidentata. J. Anhui Agric. Sci. 36(28):12306-12307.

Qin M, Xie XL, Wen CM (2015). Effects of formula fertilization on physiological and biochemical indexes and growth indexes of *Isatis indigotica* Fort. Guangdong Agric. Sci. 7:48-54.

Sales E, Kanhonou R, Carlos B (2006). Sowing date, transplanting, plant density and nitrogen fertilization affect indigo production from Isatis species in a Mediterranean region of Spain. Ind. Crop Prod. 23(1):2.

Tan Y, Liang ZS, Dong JE, Hao HY, Ye Q (2008). Effect of water stress on growth and accumulation of the active components of *Isatis indigotica*. China J. Chin. Mater. Med. 33(1):19-22.

Tang SH, Yang HJ, Huang LQ (2010). Discuss on effect of physical environmental factors on nature of Chinese material medica. China J. Chin. Mater. Med. 35(1):126-128.

Tang XQ, Wang KC, Chen X (2011). Effects of waterlogging stress on activity of alcohol dehydrogenase and peroxidase in seedlings of

Isatidis indigotica. Acta Agric. Jiangxi, 23(2):70-73.

Tian XH, Wang ZH, Liu SX (1999). Effect of different nitrogen forms and NO^- to NH^+ ratio on growth and quality of vegetables. Acta Univ. Agric. Boreali-occidentalis, 27(2):6-10.

Wang H, Wang XH, Wang YH (2008). Hairy root induction of Isatis indigotica Fort.and plantlet regeneration. Crops, 5:31-35.

Wang WB, Yu JY, and Xu JZ (2005). Effect of sowing period on motherwort growth. Res. Pract. Chin. Med. 19(3):13.

Wei SY, Zhang X, Wei CX (2004). The nutrition characteristics and planting technique of Baphicanthus Cusia Bremek. J. Mount. Agric. Biol. 22(6):493-498.

Wu XH (2008). Effect of mineral elements on the growth and accumulation of active ingredient in Isatis indigotica Fort. Hunan Agricultural University: Master's degree thesis.

Xia HP (1997). Research progress of cadmium in the soil-plant system. J. Appl. Environ. Biol. 3(3):289-298.

Xiao P, Huang HZ, Chen JW, Li X (2014). In vitro antioxidant and anti-inflammatory activities of Radix Isatidis extract and bioaccessibility of six bioactive compounds after simulated gastro-intestinal digestion. J. Ethnopharmacol. 157:55-61.

Yan FX, Wang KC, Tang XQ, Luo CH (2010). Effect of nitrogen forms on the active ingredients and mineral elements content of *Isatis indigotica* Fort. Jiangsu J. Agric. Sci. 26(4):735-739.

Yang JX, Tian YX (2004). Medicinal Plant Cultivation. Version. Beijing, China: China Agriculture Press.

Yang MH, Lu J, Xiang CZ, Yao HW (2001). Soil environmental quality and GAP of Chinese herbal medicines. China J. Chin. Mater. Med. 26(8):514-516.

Zhang JS, Meng P, Gao J (2004). Characteristics of photosynthesis and water physioecology of *Isatis indigotica*. J. Northeast For. Univ. 32(3):26-28.

Zhang SZ, Ke SY (2010). The impact of different nutrient solution on the growth and physiological characteristics of *Isatis indigotica* Fort. Guizhou Agric. Sci. 38(4):54-55.

Zhang X, He MH, Zheng WY, Wei CX (2011). Effect of cadmium pollution in soil on the main nutrient content of *Baphieaeanthus cusia* (Nees) Breme. J. Anhui Ash Sci. 39 (14): 8307-8308.