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重金属 Zn、Cd 对红树植物秋茄幼苗的
生理生态效应研究

The Ecophysiological Effect Research of Heavy Metal Zn
and Cd on Mangrove *Kandelia candel* (L.) Druce Seedlings

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摘要

本文通过土培试验方法,研究不同浓度 Zn、Cd 复合胁迫处理对红树植物秋茄 (*Kandelia candel* (L.) Druce) 幼苗生长及生理生态效应的影响。对秋茄幼苗萌发、叶绿素含量、可溶性蛋白含量、抗氧化酶系统、MDA 含量、秋茄幼苗各组分 Zn 和 Cd 含量与富集系数等生理特性方面随 Zn、Cd 复合处理梯度发生的变化进行了系统的研究,进一步探讨了红树植物抗重金属生理生态学适应机制。研究结果如下:

1 同一 Zn 水平上,秋茄的幼苗随 Cd 浓度增加而先增加后下降。同一 Cd 水平上随 Zn 浓度增加趋于下降。各处理组均未发现个体死亡现象,成活率达 100%。

2 同一 Zn 水平上,秋茄幼苗的高度生长随 Cd 浓度增加趋于下降, $100 \text{ mg} \cdot \text{kg}^{-1}$ 的 Zn 可减缓 Cd 对秋茄幼苗高度生长的抑制,此时 Zn、Cd 之间表现为拮抗作用;高浓度的 Zn、Cd 复合处理下,秋茄幼苗的高度生长受到明显的抑制, Zn、Cd 之间表现为协同作用。

3 $2.5 \text{ mg} \cdot \text{kg}^{-1}$ 的 Cd 对秋茄幼苗的叶片生长,在 Zn0 和 Zn500 水平上表现为促进作用; $100 \text{ mg} \cdot \text{kg}^{-1}$ 的 Zn 对秋茄幼苗的叶片生长也有一定的促进作用。

4 Cd 对秋茄根系生长的影响,在 Zn0 和 Zn100 水平上表现为促进作用,且根系根长随 Cd 浓度增大而增加。秋茄主根数目在 Zn100 水平上随 Cd 浓度增加而减少。中短期时间培养下, $100 \text{ mg} \cdot \text{kg}^{-1}$ 的 Zn 对秋茄主根的数目具有促进效应。

5 同一 Zn 水平上,秋茄茎生物量随 Cd 浓度增加趋于下降,根生物量和叶生物量不同时期根据 Zn、Cd 复合处理相对浓度关系不同表现出不同的变化趋势。Zn、Cd 复合处理对秋茄茎、叶、根生物量的抑制程度大致存在以下关系:茎)根)叶。

6 秋茄叶片叶绿素总量,在 Zn0 水平上随 Cd 浓度增加而降低,在 Zn100 和 Zn500 水平上随 Cd 浓度增加而先上升后下降。高浓度的 Zn、Cd 复合处理对叶绿素总量的影响表现为协同的抑制作用。随着培养时间延长,秋茄对这种抑制作用敏感性降低。中短期时间培养下,低浓度单因子 Cd 处理 ($2.5 \text{ mg} \cdot \text{kg}^{-1}$) 对

叶绿素 b 的促进作用大于叶绿素 a。

7 低浓度的 Zn、Cd 单独施加均促进秋茄根、叶可溶性蛋白增加。施加 $2.5 \text{ mg}\cdot\text{kg}^{-1}$ 的 Cd 时，在根中 Zn、Cd 之间表现为协同作用；在叶中 Zn、Cd 之间表现为拮抗作用。

8 培养 110d 时，Zn、Cd 复合处理下，秋茄根、叶 SOD 活性变化趋势相似，后者变化幅度大于前者。Zn、Cd 复合处理总体上增强秋茄根、叶 SOD 活性。低浓度 Cd 刺激秋茄根、叶 SOD 活性增加，Zn 的加入，增强了 Cd 对秋茄的毒害作用，SOD 活性受抑制而增加缓慢，其中以 $100 \text{ mg}\cdot\text{kg}^{-1}$ 的 Zn 效应最强。

9 培养 80d 时，Zn、Cd 复合处理下，秋茄根、叶 POD 活性变化趋势相似，后者变化幅度大于前者。低浓度 Cd 刺激秋茄根、叶 POD 活性增加，施加 Zn 则加强 Cd 对秋茄的伤害，POD 活性受抑制而增加缓慢，该协同抑制的效应随 Zn 浓度增加而增加，POD 活性下降。

10 Zn、Cd 复合处理下，叶片的 MDA 含量大小及变化幅度大于根尖。高浓度的 Zn、Cd 复合胁迫加剧叶片细胞的膜脂过氧化作用，MDA 含量大量增加。

11 Zn、Cd 复合处理下，秋茄各组分的 Zn 含量和 Cd 含量有较大差异。各组分 Zn 含量和 Cd 含量的大小及变化幅度的大小关系依次是：根>胚轴>茎叶。Zn、Cd 相互作用导致秋茄体内累积更多的 Cd。Zn 浓度在 $0\sim 100 \text{ mg}\cdot\text{kg}^{-1}$ 时，Cd 抑制秋茄幼苗积累更多的 Zn；Zn 浓度达到 $500 \text{ mg}\cdot\text{kg}^{-1}$ 时，土壤中的 Zn、Cd 相互作用，促进秋茄各组分（叶片除外）Zn 的累积；叶片中的 Zn 含量随 Cd 浓度增加而下降。秋茄幼苗各组分对 Zn、Cd 的富集系数存在差异性。表现为根部对 Zn、Cd 的优先富集效应。

关键词：秋茄；锌镉复合污染；生理生态

Abstract

In this paper, the soil-cultivated *Kandelia candel* (L.) Druce seedlings were treated with various contents of Cd and Zn, and the effects on the physiological properties were measured. Hypocotyl germination and growth, chlorophyll content, soluble protein, antioxidase membrane protection system, MDA content, Zn, Cd absorption accumulation character were observed to inquire into the ecophysiological responses of mangrove *Kandelia candel* (L.) Druce to Zn, Cd phytotoxicity. The results were as follow:

1 The shoot of viviparous propagules were promoted at first and then decreased with the increasing Cd contents, while the Zn contents were the same. And the shoot of viviparous propagules were decreased with the increasing Zn contents, while the Cd contents were the same. The survive rates of *Kandelia candel* (L.) Druce seedlings in difference Zn and Cd concentration were 100%.

2 The height growth of stems of *Kandelia candel* (L.) Druce seedlings was restrained under the Cd treated. But the extent of the restraint became smaller when the seedlings were treated in $100 \text{ mg}\cdot\text{kg}^{-1}$ Zn concentration because of the antagonistic effects of Zn and Cd. The height growth of stems of *Kandelia candel* (L.) Druce seedlings was restrained obviously under high Zn ,Cd concentration because of the cooperation of Zn and Cd.

3 The area of leaves in different Cd concentration of *Kandelia candel* (L.) Druce seedlings was promoted step by step under 0 or $500 \text{ mg}\cdot\text{kg}^{-1}$ Zn concentration. $100 \text{ mg}\cdot\text{kg}^{-1}$ Zn concentration also can promote the area of leaves.

4 Under 0 or $100 \text{ mg}\cdot\text{kg}^{-1}$ Zn concentration, the roots growth of of *Kandelia candel* (L.) Druce seedlings was promoted with the increasing Cd contents. Under $100 \text{ mg}\cdot\text{kg}^{-1}$ Zn concentration, the number of roots was reduced with the increasing Cd contents.

5 The stem biomass of *Kandelia candel* (L.) Druce seedlings was reduced with the increasing Cd contents. The root biomass and leaf biomass showed significant

difference in different time and concentration of Zn and Cd. Effects of different concentration of Zn and Cd on every part biomass were as follows: stem>root>leaf.

6 The synthesis of chlorophylls of *Kandelia candel* (L.) Druce seedlings was reduced with the increasing Cd contents under 0 mg•kg⁻¹ Zn concentration. But it was promoted at first and then decreased with the increasing Cd contents under 100 and 500 mg•kg⁻¹ Zn concentration. The synthesis of chlorophylls of *Kandelia candel* (L.) Druce seedlings was restrained obviously under high Zn ,Cd concentration because of the cooperation of Zn and Cd. The ratios of Chl(a/b) increased at first and then decreased with the increasing Cd contents under 500 mg•kg⁻¹ Zn concentration. The promotion to Chlb was heavier to Chla with low Cd contents.

7 Low Cd concentration or low Zn concentration accelerated soluble protein content in roots and leaves of *Kandelia candel* (L.) Druce seedlings. Under 2.5 mg•kg⁻¹ Cd concentration, the effects of Zn and Cd were antagonistic in root, while Zn cooperation in leaf.

8 The transformation trend of SOD activities was similar in roots and leaves with different concentration of Zn and Cd when it was treated 110 days, But the transformation extent of leaves was larger than roots. The activities of SOD were accelerated both in roots and leaves under low Cd concentration. Zn cooperated with Cd, especially 500 mg•kg⁻¹ Zn concentration.

9 The transformation trend of POD activities was similar in roots and leaves with different concentration of Zn and Cd when it was treated 80 days, But the transformation extent of leaves was larger than root. The activities of POD were accelerated both in roots and leaves under low Cd concentration. Zn cooperated with Cd.

10 The content and transformation extent of MDA in leaves were larger than in roots. The peroxidation of membrane fattiness was pricked up obviously under high Zn ,Cd concentration, and MDA contents increased obviously.

11 Different organs absorption to Zn and Cd showed significant differences, when the content and transformation extent of every organ ranked as follow: root>hypocotyle>stem and leaf. The interactional effects of Zn and Cd made the

seedlings absorb more Cd. In 0~100 mg•kg⁻¹ Zn concentration, absorption to Zn was restrained by Cd. But when the Zn concentration increased to 500 mg•kg⁻¹, absorption to Zn in each organ(except for leaf) was accelerated. Absorption to Zn in leaf was restrained with increasing Cd concentration. Enrichment coefficients of Zn and Cd in different organs showed significant differences. The domination of root was showed.

Keywords: *Kandelia candel* (L.) Druce; Zn-Cd complex pollution; ecophysiology

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