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Analysis on the Effects of Potassium Deficiency on the Growth and Physiological Characteristics of Coconut Seedlings

Lilan Lu*, Yuping Wang

Key Laboratory of Tropical Oil Crops Biology, Coconut Research Institute, Chinese Academy of Tropical Agricultural Sciences, Wenchang 571339, China

Abstract: Potassium ions (K^+) are crucial for plant growth and crop yield. However, the effects of low potassium on the growth and physiological characteristics of coconut seedlings remain poorly understood. Therefore, in this study, we conducted a hydroponic pot experiment to compare the changes in growth and leaf physiological traits of coconut seedlings under low potassium (K_L) and normal potassium (K_{ck}) conditions. Low potassium significantly reduced plant height, biomass, SPAD values of chlorophyll, as well as potassium (K) content, soluble protein (SP) and soluble sugar (SS) levels in coconut seedlings. Under low potassium conditions, the content of malondialdehyde (MDA) in the leaves of coconut seedlings increased significantly, while the proline (PRO) content decreased markedly. The activities of superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT) were significantly reduced. The levels of endogenous hormones such as auxin (IAA), gibberellin (GA), and zeatin (ZR) declined significantly, while the content of abscisic acid (ABA) increased significantly. The results indicate that low potassium has a substantial impact on the growth and physiological characteristics of coconut seedlings. Therefore, in coconut cultivation, it is essential to ensure the scientific and moderate supplementation of potassium fertilizers to meet their growth and physiological requirements.

Keywords: Coconut; Low Potassium; Growth; Physiological Characteristics

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1 Introduction

The coconut (*Cocos nucifera* L.) is a perennial tree belonging to the palm family (Palmae) and serves as a vital multifunctional tropical crop in food, energy, daily necessities, and chemical production. Additionally, it is consumed as a fresh fruit, making it a significant high-value tropical fruit and oil crop, as well as a unique renewable, green, and environmentally friendly resource in tropical regions [1]. Coconuts are potassium-loving plants, requiring substantial potassium during their growth and development. Since coconut water contains high levels of potassium, sufficient potassium must be absorbed from the soil during fruit development to avoid affecting its growth.

Previous studies have shown that, apart from soil, coconuts heavily rely on organic and chemical fertilizers as external sources of potassium [2, 3]. Mild to moderate potassium deficiency can cause yellowing and necrosis of old leaves in coconuts, while severe cases may lead to yellowing and wilting of new leaves, resulting in reduced photosynthesis, weakened immunity, and increased susceptibility to pests and diseases [4, 5]. Potassium deficiency also decreases the number of female flowers in

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*Corresponding author: Lilan Lu, lulilan1234@163.com

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coconuts, leading to poor pollination, flower drop, fruit drop, and poor development of young fruits [6, 7]. Additionally, it significantly reduces the yield and quality of mature coconut trees [8, 9]. Potassium deficiency can cause root aging and rotting in coconut trees [10-12]. These findings highlight the critical importance of potassium for coconut growth and development, making research on its physiological effects particularly vital. In this study, we conducted hydroponic experiments with potted coconut seedlings to compare the physiological changes in leaves under potassium-deficient and potassium-sufficient conditions, aiming to provide a foundational reference for improving potassium utilization in coconuts.

2 Materials and Methods

2.1 Materials and Experiments

The growth of Yellow dwarf (Wenye No. 2) coconut seedlings after seed and fruit cultivation, removal of seed and fruit, restoration, and potassium treatment after transplantation. Remove the coconut seedlings that have sprouted and grown for 1.5 months, then restore them in a nutrient bag for 15 days. Select seedlings of the same size, height, and number of leaves and transfer them to a hydroponic system (using nutrient free quartz sand and vermiculite (20: 6) (50×37×35 cm) as the substrate). Coconut seedlings were randomly divided into 2 groups (15 plants per treatment) Each treatment has 3 biological replicates, each replicate containing 5 plants. After pre culturing for 10 days, stress treatment begins. The sufficient potassium content of coconut seedlings is determined based on the potassium content standard of coconut leaves. The concentration of sufficient potassium is selected, and 0.1 mM potassium chloride (K^+ deficiency) is added; K_L) treatment and 6 mM potassium chloride (K^+ sufficient; K_{ck}) nutrient treatment solution (other nutrient element concentrations were irrigated every 3 days according to the Hogland nutrient solution standard [13] to evaluate their response, lasting for 30 days. Plant height was measured and samples were collected. Coconut leaves, some of which were used for physiological index analysis, were immediately frozen in liquid nitrogen and stored at -80 ℃ until use. The other part of the sample is dried for mineral nutrient nitrogen, phosphorus, and potassium detection and analysis.

2.2 Coconut Seedling Height, Dry Weight, and SPAD Detection

Measure the plant height with a tape measure (accuracy 1mm); Measure the SPAD value of coconut leaves using a SPAD (soil and lant analyzer development) chlorophyll analyzer (CHLOROPHYLL METER SPAD-502 Plus, Konica Minolta, Japan). To evaluate the dry weight (DW) of coconut seedlings, the dry stem and root parts were measured at 105 ℃ for 15 min and 70 ℃ for 72 h. Based on these data, we calculated the DW (stem+root) of the entire plant.

2.3 Analysis of Leaf Tissue Structure

Firstly, paraffin sections are deparaffinized to water: the sections are sequentially placed in environmentally friendly dewaxing transparent solution I for 20 min, environmentally friendly dewaxing transparent solution II for 20 min, anhydrous ethanol I for 5 min, anhydrous ethanol II for 5 min, 75% alcohol for 5 min, and washed with tap water. Next, perform safranin staining: Slice and stain in plant safranin staining solution for 2 min, then rinse with tap water to remove excess dye. Then, decolorization: the slices are sequentially immersed in 50%, 70%, and 80% gradient alcohol for 3-8 s each. Then, fixation green staining: the slices are immersed in plant fixation green staining solution for 6-20 s, and dehydrated in three tanks of anhydrous ethanol (time: 5/10/20 s). Then, transparent sealing: slice into clean xylene and clear for 5 min, and seal with neutral gum. Finally, microscopic examination (Nikon Eclipse E100, Japan) and image acquisition analysis (Nikon DS-U3, Japan) were performed.

2.4 Detection of Mineral Nutrients N, P, and K in Leaves

The leaves were digested with HNO_3-$HClO_4$ and then subjected to N, P, and K measurements. N adopts alkaline hydrolysis diffusion method. P adopts molybdenum antimony colorimetric method. K adopts the AAS method (atomic absorption spectrophotometer model: SHIMADZUAA6300F, Agilent, USA), and the operation method refers to the method of Bao (2000) [14].

2.5 Detection of Leaf Nutrients, Endogenous Hormones, and Oxidase Activity

The soluble sugar (SS) content was determined using the anthrone colorimetric method. The soluble protein (SP) content was determined using the Coomassie Brilliant Blue G-250 method. The content of endogenous hormones such as indole-3-acetic acid (IAA), gibberellin (GA), abscisic acid (ABA), and zeatin (ZR) was determined using enzyme-linked immunosorbent assay (ELISA), following the method proposed by Li (2000) [15]. The content of malondialdehyde (MDA), proline (PRO), superoxide dismutase (SOD) activity, catalase (CAT) activity, and peroxidase (POD) were determined using the method of Li (2000). The detection kit was sourced from Nanjing Jiancheng Bioengineering Research Institute and operated according to the kit instructions. Repeat each experiment three times and calculate the average of the three repetitions.

2.6 Data Analysis

All experiments were conducted with 3 replicates (n=3), and statistical analysis was performed using SPSS 20.0 software (SPSS Inc., Chicago, IL, USA) for one-way analysis of variance (ANOVA). A probability value of $p<0.05$ indicates that the difference is statistically significant. I have written some charts and data using Excel 2020. The data is presented as the mean ± standard deviation (SD) of three replicates.

3 Results and Analysis

3.1 Effects of Low Potassium on Leaf Structure of Coconut Seedlings

In order to analyze the tissue structure of coconut leaves under low potassium stress, the structural changes of coconut seedling leaves were observed through paraffin sections under low potassium conditions (K_L) and control (normal potassium supply conditions) (K_{ck}). Observations have shown that according to the principle of lignified cell walls appearing red and cellulose cell walls appearing green. The structural changes of coconut leaves in the control treatment were minimal, and the cell structure was normal. However, under low potassium conditions, the cell wall of coconut leaves showed extensive lignification and thrombosis, while the cytoplasm, nucleus, and ducts also underwent significant changes (Figure 1).

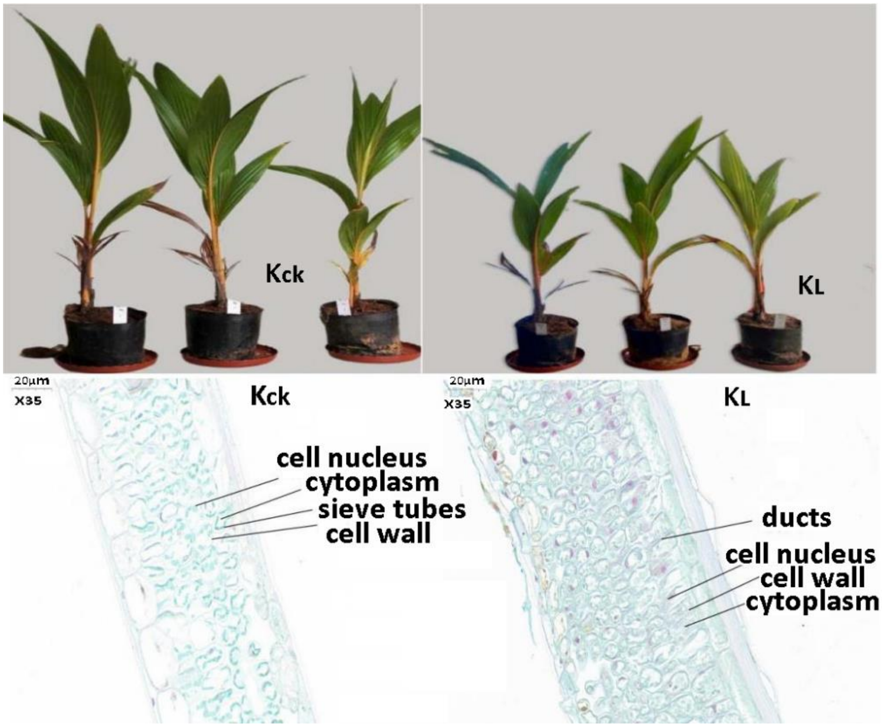

Figure 1 Effects of Low Potassium on Coconut Growth and Structure

3.2 Effects of Low Potassium on the Growth of Coconut Seedlings, Leaf SPAD, Mineral Nutrients, and Nutrients

In order to investigate the mechanism of the effects of low potassium on the growth, leaf SPAD, mineral nutrition, and nutrient substances of coconut seedlings, a low potassium treatment pot experiment was conducted on coconut seedlings to study their response to low potassium (0.1 mM K^+) (K_L). The results of this study showed that K_L treatment significantly reduced the plant height and fresh weight of coconut seedlings ($p<0.05$), by 21.83% and 26.45%, respectively (Table 1). In addition, under K_L conditions, SP significantly decreased by 24.83% ($p<0.05$), while SS content significantly increased by 33.43% (Figure 2). Under K_L conditions, the K, N, and P content in coconut seedling leaves decreased, while the K concentration significantly decreased by 48.36% (Table 2). Under K_L conditions, the SPAD value was significantly lower than the control (K_{ck}) ($p<0.05$) (Figure 2). Therefore, low potassium severely affects the biomass and mineral nutrients, photosynthetic physiological indicators, and quality of coconut seedlings.

Table 1 Dry weight and plant height under K_{ck} and K_L treatments

Treatments	Plant height (cm)	Dry weight (g/plant)
K_{ck}	112.70±2.36^a	163.67±0.42^a
K_L	88.10±1.56^b	120.38±0.16^b

Note: The data represents mean±standard deviation (n=3). The different lowercase letters following the values of each organization in the same column indicate significant differences between treatment groups ($p<0.05$).

Table 2 Changes in mineral nutrient content in coconut leaves under K_{ck} and K_L Treatments

Treatments	Mineral and nutrient element content in leaves (%, DW)		
	K	N	P
K_{ck}	1.22±0.091^a	1.86±0.093^a	0.111±0.006^a
K_L	0.63±0.023^b	1.48±0.074^a	0.101±0.002^a

Note: The data represents mean±standard deviation (n=3). The different lowercase letters following the values of each organization in the same column indicate significant differences between treatment groups ($p<0.05$).

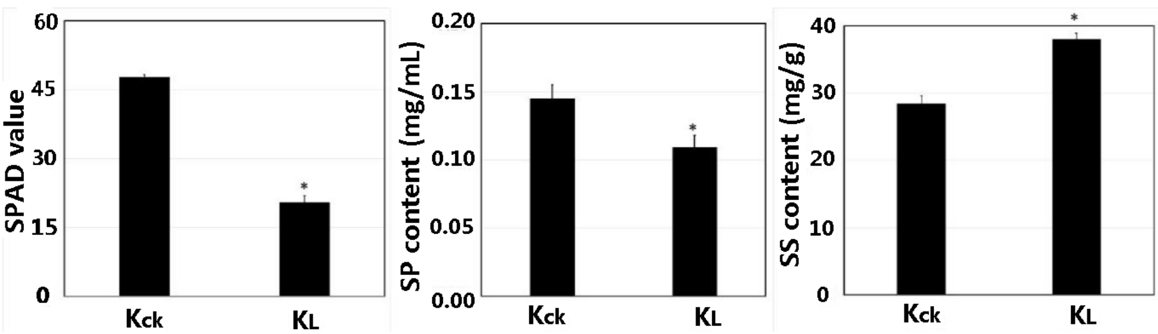

Figure 2 The effects of low potassium on SPAD, SP, and SS in coconut seedlings. Perform ANOVA (one-way ANOVA) between K_{ck} and K_L for statistical analysis, with * $p<0.05$. The bar chart represents ±standard error (±SD)

3.3 Effects of Low Potassium on Oxidase Activity and Endogenous Hormones in Coconut Seedling Leaves

Low potassium conditions have a significant impact on the physiology of coconut seedlings (Figure 3). Under K_L conditions, MDA content significantly increased by 29.11%, while PRO content significantly decreased by 39.41% ($p<0.05$). Compared with K_{ck}, the activities of CAT, POD, and SOD in the leaves were significantly reduced by 16.44%, 16.34%, and 20.16% ($p<0.05$). In addition, potassium deficiency stress had a significant impact on endogenous hormones in coconut seedling leaves. Under K_L conditions, ABA content increased significantly by 50.68% ($p<0.05$), while IAA, ZR, and GA decreased significantly by 22.56%, 23%, and 21.13%, respectively

(p<0.05) (Figure 3). Therefore, low K seriously affects the physiological function indicators and hormone levels of coconut seedlings.

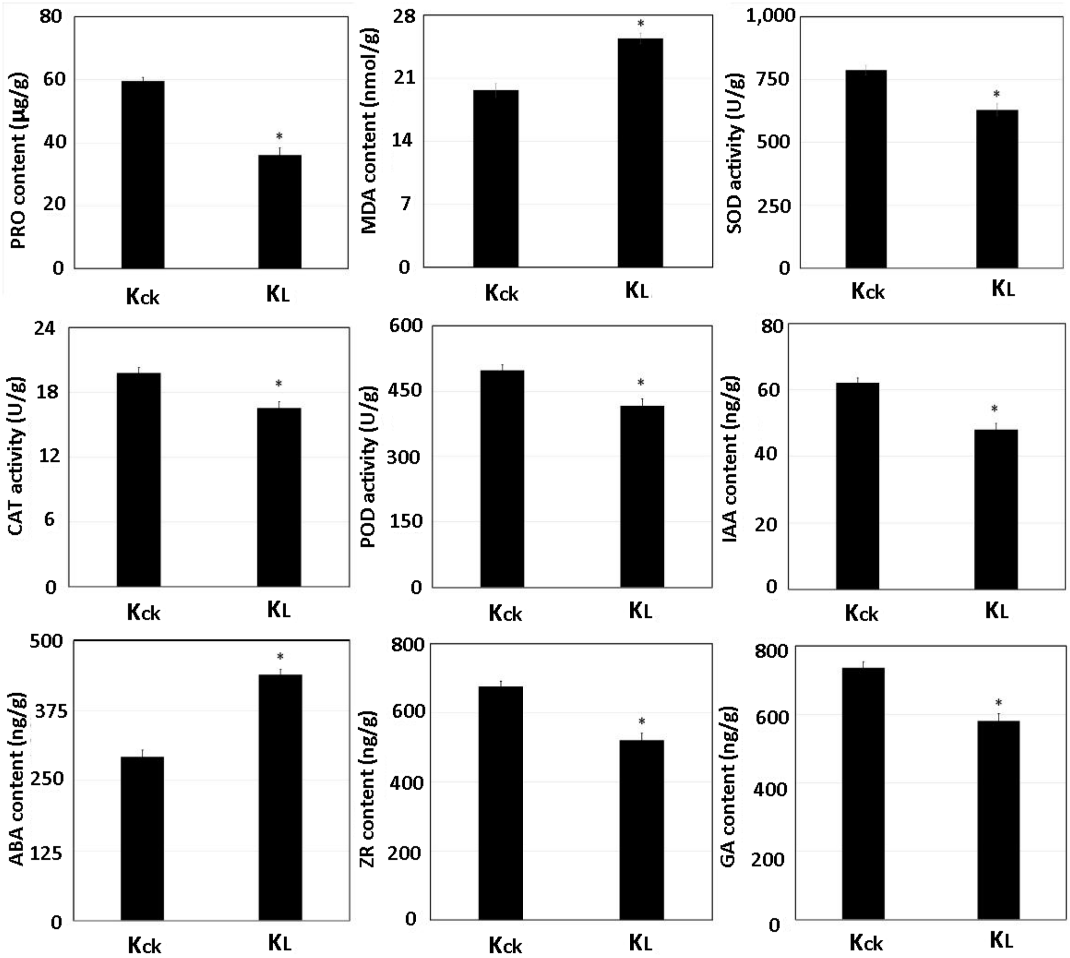

Figure 3 The effects of low K on the contents of MDA, Pro, IAA, GA, ABA, and ZR, as well as the activities of SOD, CAT, and POD in coconut seedlings. Note: Statistical analysis was conducted using one-way ANOVA between the K_L and K_{ck} treatments groups, with * p<0.05. The bar chart represents ±standard error (±SD)

4 Discussions

K^+ deficiency leads to limited coconut growth, significant decrease in whole plant biomass and fruit yield. Applying potassium fertilizer can promote coconut growth and increase total biomass and yield, indicating that potassium directly affects coconut biomass and yield [11]. As for coconuts, most research has focused on the potassium content during coconut growth and its impact on yield, rather than the effects of potassium on coconut growth and physiological mechanisms [10]. Due to potassium deficiency, the height of coconut seedlings decreases, significantly limiting plant growth and resulting in a decrease in fresh weight. Low potassium stress significantly reduces the biomass of seedlings.

Under low potassium conditions, the K, N, and P content in coconut seedling leaves decreased, while the K concentration significantly decreased by 48.36%. K^+ plays an important role in photosynthesis by converting radiation energy into chemical energy through the production of ATP. Severe K^+ deficiency can reduce photosynthesis [16]. The absorption efficiency of K^+ in the root system is relatively low, significantly reducing the content of K in leaves (compared with the control, it decreased by 48.36%), reducing photosynthesis, and inhibiting plant growth [17, 18]. In addition, leaves and stems serve as sinks for K^+ and carbon assimilation during plant growth, and plant growth retardation is a feedback signal for K^+ deficiency [19]. In addition, studies have shown that compared to normal potassium application levels (200 μmol/L), the biomass of tea tree roots, stems, and leaves decreases under low potassium conditions, and the content of N and P in leaves significantly decreases [20]. The lack of K element can lead to a decrease in the content of mineral nutrients related to photosynthesis in banana leaves [21]. Therefore, this study also indicates that low potassium reduces the K, N, and P content in coconut seedling leaves, with the most significant decrease in content.

Under low potassium conditions, the SPAD value was significantly lower than that of the control group. Potassium deficiency stress reduced growth and biomass, which may be due to an increase in reactive oxygen species (ROS) in coconut seedlings caused by potassium deficiency, resulting in a decrease in chlorophyll. This may also lead to a decrease in SPAD value of coconut seedling leaves under low potassium conditions. The activity of antioxidant enzymes in plant cells is stimulated by environmental stress. Reactive oxygen species scavenging enzymes such as SOD, CAT, and POD play important roles in plant antioxidant stress [22]. Under low potassium conditions, the activities of CAT, POD, and SOD in coconut seedling leaves were significantly reduced. The PRO content also significantly decreased. Low potassium stress inhibits the activity of MDA in coconut seedling leaves and shows significant activity under low potassium conditions, which may lead to more accumulation of MDA. In addition, in this study, in addition to a significant increase in ABA, endogenous hormones IAA, GA, and ZR significantly decreased under low potassium stress conditions, indicating that low potassium stress has a greater impact on endogenous hormones in coconut seedling leaves. Previous studies have shown that under potassium deficiency stress, the growth of the roots and aboveground parts of walnuts, as well as the synthesis of photosynthetic pigments, are significantly affected. However, walnuts can increase their absorption capacity by regulating themselves and increasing the input to the roots. And by increasing heat dissipation to consume the excess excitation energy of the PSII reaction center, the damage to the photosynthetic apparatus caused by stress is reduced, and the enzymatic antioxidant system and hormones in the body are mobilized to undergo changes, resulting in a significant decrease in the activities of PRO, CAT, POD, and SOD. Inducing changes in endogenous hormones. This enhances the ability to resist damage from low potassium stress to a certain extent [23]. Research has shown that potassium deficiency leads to a decrease in the content of soluble proteins, soluble sugars, and other carbohydrates in crops, as well as a decrease in chlorophyll content [24-26]. This study also indicates that low potassium severely affects the physiological characteristics and hormone levels of coconut seedlings.

5 Conclusion

This study compared the growth, nutrient composition, and physiological analysis of coconut seedlings under K_L and K_{ck} conditions. The results showed that the growth, nutrients, antioxidant enzyme activity, and endogenous hormones of coconut seedlings were also affected by low potassium stress. Due to the important role of potassium in coconut growth, biomass, quality, yield, and resistance to pathogens, improving the utilization efficiency of plant potassium is essential. Low potassium on coconut growth and physiological analysis, and further research will lay the foundation for improving potassium utilization efficiency in the future.

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