Effects of alginic acid on phosphorus and potassium absorption in radish under cadmium contamination

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Abstract. In order to study the effects of alginic acid at different dilution folds on phosphorus and potassium absorption of radish under cadmium contamination, foliar application of radish seedlings was carried out using alginic acid solutions with different dilution folds. The results showed that the alginic acid solution at 600, 900, 1200, and 1500 dilution folds increased the potassium content of radish, and increased the content of available phosphorus and available potassium in the soil. The solution of lower dilution folds (600 and 900) increased phosphorus content of radish, while the solution with higher dilution folds (1200 and 1500) only increased phosphorus content in radish roots and root tubers. It showed that foliar application of alginic acid could alleviate the harm of cadmium stress to radish to a certain extent, and increase the absorption of phosphorus and potassium nutrients in radish. The best effect was achieved when the dilution fold of alginic acid solution was 600.

1. Introduction

At present, heavy metal pollution of soil and water is very serious, which poses a serious threat to the ecological environment, plant growth and human health [1, 2]. Among all kinds of heavy metal pollution, cadmium is especially harmful. Cadmium has the characteristics of strong biological migration, easy absorption and accumulation by plants, and can produce toxic effects on animals, plants and human bodies [3]. Cadmium has physiological toxicity to most plants. Under high cadmium stress, plant growth and development will suffer a series of damages [4], including the destruction of photosynthetic mechanisms [5], the disorder of the oxidation system [6], the impact of mineral nutrient absorption, and eventually leading to a reduction in crop yield and quality [7]. In recent years, cadmium pollution of farmland soil has become more and more serious due to sewage irrigation, improper fertilization, industrial activities, mining and other reasons, especially in vegetable soil [8]. This not only has a great threat to human health, but also has a serious impact on the quality and safety of vegetable products [9].

Alginic acid is a kind of natural polysaccharide polymer widely existing in marine plants (such as kelp, seaweed) [10]. The new botanic preparation is biodegradable, pollution-free, relatively non-toxic and has a broad application prospect [11]. Alginic acid is often used as a biological stimulant in agricultural applications. Alginic acid can promote plant growth. The application of alginic acid...
soluble foliar fertilizer on cucumber leaves could promote the growth and development of cucumber and the improvement of various economic properties of cucumber [12]. Alginic acid can also improve the quality of crops. Zhong and others sprayed alginic acid foliar fertilizer on soybeans, which improved the effective branch number, plant height and 100 grain weight of soybeans, and significantly improved the yield of soybeans [13]. In addition, alginic acid also plays an important role in increasing plant resistance to help plants resist biological and abiotic stresses [14]. Alginic acid can alleviate the damage of low temperature stress on tobacco, which was mainly manifested in increasing photosynthetic rate, reducing sugar and proline content, and reducing H$_2$O$_2$ content in leaves [15]. Under drought stress, seaweed extract containing alginic acid promotes the growth of spinach, and reduces the increase of gas exchange inhibition and stomatal limitation induced by drought stress [16]. Therefore, alginic acid can alleviate the damage caused by stress to plants.

Radish (Raphanus sativus) is one of the most economically important annual or biennial root vegetable crops [17]. It has the advantages of high nutritional value and strong adaptability. The main edible part of radish is fleshy root tubers. As an organ that contacts the soil environment in all directions, the root can preferentially absorb and accumulate various heavy metal elements and other ions in the soil [18]. Therefore, the heavy metal pollution of radishes is more serious. In this experiment, alginic acid solutions with different dilution folds were applied to radish under cadmium contamination, and the effects of alginic acid solutions with different dilution folds on phosphorus and potassium nutrient absorption of radish under cadmium contamination were studied, so as to provide a basis for the cultivation of the radishes under the cadmium contamination.

2. Materials and methods

2.1. Materials

The radish variety was "red-skinned radish", an early-maturing variety that was purchased on the market. Alginic acid was purchased on the market. The soil was taken from the farmland around Gongping Town, Wenjiang District, Chengdu, Sichuan Province, China. It was a fluvo-aquic soil. Its basic physical and chemical properties were pH 7.58, organic matter 28.02 g/kg, total nitrogen 1.44 g/kg, total phosphorus 0.43 g/kg, and total potassium 24.55 g/kg, alkaline nitrogen 58.68 mg/kg, fast-acting phosphorus 19.23 mg/kg, fast-acting potassium 58.33 mg/kg, and available cadmium content was not detected.

2.2. Experimental design

The soil was air-dried and pulverized. After passing through a 6.72 mm sieve, it was placed in a plastic circular flower pot of 15 cm × 18 cm (height × diameter). Each pot was filled with 3.0 kg of soil, and CdCl$_2$.2.5H$_2$O Add to the soil and mix to make the soil cadmium concentration 5 mg/kg. After that, keep the soil moist so that its water content is about 80% of the soil water capacity in the field. Leave it for 1 month and mix it from time to time to ensure that the soil is fully mixed. In September 2019, the radish seeds were directly sown in pots filled with the prepared cadmium contamination, and 10 seeds were evenly spread in each pot. When the radish seedlings emerged and grew to two true leaves, reduced the number of seedlings in the pot, and kept 4 healthy radish seedlings with consistent growth in each pot. Then spray the alginic acid solution with different concentrations on the leaves of the radish seedlings, the spraying amount shall be based on the dripping of the leaves. The alginic acid concentration was diluted 0, 600, 900, 1200, and 1500 dilution folds according to its original solution, and each treatment was repeated 3 times (3 pots). During the entire growth process of radish, water is often used to keep the soil in the pot moist. At the same time, the position of the pot and pot is exchanged irregularly to reduce the marginal effect, and weeds are removed in time to prevent and treat pests and diseases. 40 days after spraying alginic acid, harvested the plant samples were collected for determination of related indicators.

2.3. Determination of items and methods

The whole radish plants were harvested, washed with tap water, and rinsed three times with deionized water. After separating the roots, root tubers and leaves of the plant, each organ of the radish materials were blanced at 110 °C for 15 min, dried at 80 °C until reaching a constant weight, and weighed (determine the dry weight of roots, root tubers and leaves). The dried tissue samples were finely
ground for a subsequent chemical analysis. Phosphorus content of radish organs was determined by the Mo-Sb anti-colorimetry, and potassium content by flame photometry according to Bao (2000) [19]. The soil in pots were air-dried and ground into a powder (soil particle diameter < 1 mm), and the available phosphorus content in the soil was determined by the Mo-Sb anti-colorimetry, while the available potassium content was determined by flame photometry [19].

2.4. Data processing method

Data were analyzed using SPSS20.0 for variance analysis (Duncan's new complex range method for multiple comparisons).

3. Results

3.1. Phosphorus content of radish

Compared with the control group, the application of alginic acid increased the phosphorus content of radish roots and root tubers under cadmium contamination (Table 1). The alginic acid solution with diluents folds of 600 and 900 increased the phosphorus content in the leaves and edible parts of the radish under cadmium contamination, while the alginic acid solution with diluents folds of 1200 and 1500 decreased the phosphorus content in the leaves and edible parts of the radish. With the increase of dilution folds, the phosphorus content in each part of radish decreased. When the dilution fold was 600, the phosphorus content of radish roots, root tubers, leaves and edible parts were the highest, which increased by 59.04% ($p < 0.05$), 23.24% ($p < 0.05$), 10.48% ($p < 0.05$) and 10.89% ($p < 0.05$), respectively, compared with the control group.

| Treatments (dilution folds) | Roots (mg/g DW) | Root tubers (mg/g DW) | Leaves (mg/g DW) | Edible parts (mg/g DW) |
|-----------------------------|-----------------|----------------------|-----------------|----------------------|
| 0                           | 5.058±0.086e    | 4.179±0.050d         | 4.092±0.071b    | 4.095±0.066b         |
| 600                         | 8.044±0.072a    | 5.150±0.102a         | 4.521±0.041a    | 4.541±0.036a         |
| 900                         | 7.073±0.120b    | 4.928±0.035b         | 4.521±0.089a    | 4.538±0.085a         |
| 1200                        | 6.710±0.018c    | 4.527±0.105c         | 3.876±0.072c    | 3.902±0.074c         |
| 1500                        | 6.005±0.065d    | 4.503±0.095c         | 3.606±0.055d    | 3.642±0.056d         |

Values are means (±SE) of three replicate pots. Different lowercase letters within a column indicate significant differences based on one-way analysis of variance in SPSS 20.0 followed by the least significant differences at the 5% confidence level. Phosphorus content in edible part biomass = (root biomass × root phosphorus content + leaf biomass × leaf phosphorus content)/ edible part biomass. Edible part biomass = root tuber biomass + leaf biomass. DW = dry weight.

3.2. Potassium content of radish

Compared with the control group, the application of alginic acid significantly increased the potassium content of each part of the radish under the cadmium contamination, and when the dilution fold was 600, the potassium content of the roots, root tubers, leaves and edible parts of the radish reached the maximum value, which increased by 84.39% ($p < 0.05$), 26.26% ($p < 0.05$), 29.93% ($p < 0.05$) and 29.82% ($p < 0.05$), respectively, compared with the control (Table 2). With the increase of dilution folds, the potassium content of each part of radish decreased.

3.3. Available phosphorus content of soil

The content of available phosphorus in the control group was the lowest, 9.49 mg/kg (Figure 1). When the dilution fold was 600, the content of available phosphorus was the highest, 21.93 mg/kg. Under the condition of alginic acid treatment, the content of soil available phosphorus increased. With the increase of dilution folds, the content of soil available phosphorus in each treatment increased by 131.09% ($p < 0.05$), 76.08% ($p < 0.05$), 51.53% ($p < 0.05$), and 6.95% ($p < 0.05$) respectively, compared with the control.

3.4. Available potassium content of soil
Compared with the control, foliar application with alginic acid increased the soil available potassium content (Figure 2). When the dilution folds were 1200 and 1500, the soil available potassium content was not significantly different from the control. When the dilution fold was 600, the soil available potassium content was the largest, which was 86.56 mg/kg. With the increase of the dilution folds, the soil available potassium content increased successively, which were increased by 13.89% \((p < 0.05)\), 5.64% \((p > 0.05)\), and 1.42% \((p > 0.05)\) higher than the control.

| Treatments (dilution folds) | Roots (mg/g DW) | Root tubers (mg/g DW) | Leaves (mg/g DW) | Edible parts (mg/g DW) |
|-----------------------------|-----------------|-----------------------|------------------|-----------------------|
| 0                           | 35.04±0.91c     | 62.38±1.59d           | 62.35±1.15d      | 62.35±1.17d           |
| 600                         | 64.61±0.89a     | 78.76±0.73a           | 81.01±0.92a      | 80.94±0.87a           |
| 900                         | 49.79±0.83b     | 75.96±0.94ab          | 72.92±1.58b      | 73.04±1.55b           |
| 1200                        | 45.44±0.02c     | 74.37±1.62b           | 72.37±1.05b      | 72.45±0.95b           |
| 1500                        | 42.33±0.43d     | 66.18±0.52c           | 67.80±1.45c      | 67.74±1.41c           |

Values are means (±SE) of three replicate pots. Different lowercase letters within a column indicate significant differences based on one-way analysis of variance in SPSS 20.0 followed by the least significant differences at the 5% confidence level. Potassium content in edible part biomass = (root biomass × root potassium content + leaf biomass × leaf potassium content)/ edible part biomass. Edible part biomass = root tuber biomass + leaf biomass. DW = dry weight.

**Figure 1.** Effect of alginic acid at different dilution folds on soil available P content. Values are means (±SE) of three replicate pots. Different lowercase letters within a column indicate significant differences based on one-way analysis of variance in SPSS 20.0 followed by the least significant differences at the 5% confidence level.

**Figure 2.** Effects of alginic acid with different dilution folds on soil available K content. Values are means (±SE) of three replicate pots. Different lowercase letters within a column indicate significant differences based on one-way analysis of variance in SPSS 20.0 followed by the least significant differences at the 5% confidence level.

**4. Discussion**

Cadmium has a negative effect on mineral content in plants, and the imbalance of mineral balance in plants is an important mechanism for cadmium to induce plant toxicity [20]. As an ion, heavy metals either compete with nutrients for plant root absorption sites, or affect plant physiological and biochemical processes, thus causing changes in plant nutrient absorption performance and transport.
characteristics [21]. The concentration of 10 μmol/L cadmium can reduce the absorption of potassium, phosphorus and other mineral elements by the root of *Stylosanthes guianensis* [22], and the concentrations of 2, 5, 8 mg/L cadmium reduces the phosphorus content of celery stems and leaves [23]. Under cadmium stress, the nitrogen, phosphorus and potassium content in the upper part of rye grassland decreases significantly compared with the control [21].

Cadmium stress can have serious negative effects on the growth of plants, but there are some agronomic measures such as hybridization, grafting and plant hormones can promote the growth and nutrient uptake of plants [24-30]. Some studies have shown that alginic acid and its oligosaccharides can significantly promote root growth. 10-50 mg/L alginic acid treatment can significantly increase the root length, number of root tips, root volume and fresh weight of *Brassica campestris*, which are necessary conditions for the formation of a large-scale and vigorous metabolism root system, and provide a guarantee for the root system to better absorb and transport water and inorganic nutrients, and to synthesize physiologically active substances [31]. Another experiment also showed that low concentration of alginic acid and its oligosaccharide can significantly promote the absorption of nitrogen, phosphorus, calcium, magnesium and other elements in *Brassica campestris* [32]. Appropriate concentration of sodium alginic acid oligosaccharide irrigation treatment can significantly improve the activities of urease and phosphate invertase in wheat rhizosphere soil, improve wheat root microenvironment, and promote the conversion of organic nutrients to inorganic nutrients, which is conducive to crop absorption and utilization [33]. When wheat is treated with synergistic phosphate fertilizer containing alginic acid, the utilization rate of phosphate fertilizer increases by 23.06% compared with the control, indicating that alginic acid can improve the utilization efficiency of phosphate fertilizer and increase wheat yield [34]. Appropriate amount of alginic acid fertilizer synergist can promote the root growth of non-heading Chinese cabbage, improve the root length, root surface area and root volume, promote nutrient absorption and root growth, and increase the yield of non-heading Chinese cabbage [35]. The nitrogen, phosphorus and potassium contents in root of strawberry sprayed with alginic acid fertilizer has no significant difference compared with the control, but the nitrogen, phosphorus and potassium contents in the shoot are significantly higher than the control. It indicates that alginic acid fertilizer solution promotes the nutrient absorption and transport from the root to the stem of the strawberry, and improves the nutrient content of the strawberry plant leaves [36]. Alginic acid derivatives can improve the resistance of plants to heavy metals. Alginic acid-derived oligosaccharides (ADO) can effectively inhibit the production of micronuclei and chromosomal aberrations of *Vicia faba* root cells under cadmium stress, and improve the mitotic index of *Vicia faba* root cells, which shows that ADO can significantly alleviate the damage of *Vicia faba* root tip cells by Cd²⁺ [37]. The treatment of alginic acid-derived oligosaccharides can alleviate the cadmium toxicity of rice to a certain extent, and the effect is the most significant when the cadmium concentration is 20 mg/L, which shows that it can promote the growth of seedlings, increase the content of photosynthetic pigment and increase the activity of antioxidant enzymes [38]. A series of studies have shown that alginic acid and its derivatives can increase the absorption of nutrients by plants and alleviate the damage caused by heavy metal stress to plants. In this experiment, alginic acid increased the content of potassium in roots, root tubers, leaves and edible parts of radish, and the content of available phosphorus and available potassium in soil under cadmium contamination. The content of phosphorus in roots and root tubers of radish under cadmium contamination was increased by alginic acid solution of all dilution folds, but only the lower dilution folds (600 and 900) of alginic acid solution improved the phosphorus content of leaves and edible parts of radish under cadmium contamination. The result showed that spraying alginic acid on the leaves could alleviate the harm of cadmium stress on radish to a certain extent, and increase the absorption of phosphorus and potassium nutrients in radish, and the best effect was achieved when the dilution fold of alginic acid solution was 600.

5. Conclusions
The alginic acid solution at 600, 900, 1200, and 1500 dilution folds increased the potassium content of radish, and increased the content of available phosphorus and available potassium in the soil. The solution of lower dilution folds (600 and 900) increased phosphorus content of radish, while the
solution with higher dilution folds (1200 and 1500) only increased phosphorus content in radish roots and root tubers. It showed that foliar application of alginic acid could alleviate the harm of cadmium stress to radish to a certain extent, and increase the absorption of phosphorus and potassium nutrients in radish. The best effect was achieved when the dilution fold of alginic acid solution was 600.

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