Effects of Phosphorus Level on Quality Traits and Quality-Related Enzymatic Activity in Lettuce

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Abstract

In this experiment, we studied the effects of the application of various amounts phosphorus on the quality traits and quality-related enzyme activity in lettuce. When we supplied lettuce with 0.3 mmol/L or 0.4 mmol/L phosphorus, the yield was higher than that of the control. In addition, the quality traits were better, the nitrate content was lower and the nitrate reductase, catalase and ascorbic acid oxidase activities were higher in these plants than in the control. In addition, the chlorophyll content was higher, and the root activity was stronger, in plants supplied with 0.3 or 0.4 mM/L phosphorus than in the control. These results suggest that the application of 0.3 or 0.4 mM/L phosphorus to lettuce is optimal for plant growth.

Introduction

Phosphorus is one of the most important elements that are required for crop growth. Phosphorus is required for many physiological and biochemical processes in plants, including photosynthesis and carbohydrate synthesis, transformation, nitrogen metabolism and adipose synthesis, and it has an important effect on the growth, yield and quality vegetables^{1,2,3}. However, due to the long-term emphasis on the application of nitrogen and potassium to crops, fertilizers have a relative lack of phosphorus, which is the biggest obstacle to optimal vegetable production. If plants lack phosphorus, protein synthesis is blocked. This seriously impacts plant growth, nitrate absorption and assimilation⁴.

Lactuca sativa L., commonly known as lettuce, belongs to asteraceae, genus *Lactuca*. Lettuce, an annual or biennial herb, is one of the four vegetables that are grown by soilless cultivation in worldwide. The cultivation area of lettuce continues to expand, as lettuce has been greatly enjoyed by consumers in recent years. To achieve high production quality, chemical fertilizers are often utilized in vegetable cultivation⁵. The incorrect application of fertilizer is one of the most important factors that affect the yield and quality of vegetables. Recent studies have focused on the effects of the level of nitrogen application, nitrogen form and ratio and the amount of potassium on the growth and development of leafy vegetables, as well as nitrate accumulation^{6,7,8}, but studies on the effects of phosphorus on leafy vegetable growth and development have been limited to the study of nitrate, most of which is single factors^{9,10}. Therefore, it is important to conduct an in-depth, systematic study on the effects of phosphorus on lettuce.

In this study, we grew lettuce plants in soil with fixed levels of nitrogen and potassium and varied amounts of phosphorus to study the effects of phosphorus levels on plant physiological indicators, quality-related enzyme activity, production and quality. The aim of this study was to determine an economically feasible and effective level of phosphorus for the production of high-yielding, high-quality lettuce to enhance the efficient production of this crop.

Results And Discussion

Results

Effects of different phosphate levels on nitrate content and nitrate reductase activity in lettuce

The effects of different phosphate levels on nitrate content and nitrate reductase activity of lettuce are shown in Figure 1. As the phosphorus concentration increased, the nitrate levels generally decreased; only treatment 6 increased the nitrate levels slightly. These results show that phosphorus levels are closely related to nitrate absorption and nitrogen metabolism. As the phosphorus concentration increased, nitrate reductase activity increased, followed by a decline. The nitrate reductase activity was significantly higher in treatment 4 plants than in the other treatments, while nitrate reductase activity was the lowest in treatment 1 plants. These results indicate that nitrate reductase activity is closely related to nitrate content.

Effects of different phosphate levels on catalase and ascorbate oxidase activity in lettuce

The effects of different phosphate levels on the activity of catalase and ascorbate in lettuce are shown in Figure 2. As phosphorus levels increased, the hydrogen peroxide enzyme activity generally increased; only treatment 6 produced a relative decline in enzyme activity. These results illustrate that catalase activity is closely related to plant metabolism. With increasing levels of phosphorus, ascorbic acid oxidase activity first increased, followed by a decline. There was no significant difference between the ascorbic acid oxidase activity levels in treatments 4 and 5, but these levels were significantly higher than in other treatments, and treatment 1 produced the lowest ascorbic acid oxidase activity level; ascorbic acid oxidase activity is closely related to plant stress resistance.

Effects of different phosphate levels on chlorophyll content and root activity in lettuce

The effects of different phosphate levels on chlorophyll content and root activity in lettuce are shown in Figure 3. As the phosphorus content increased, the chlorophyll content increased, but treatment 6 led to significantly decreased chlorophyll content. These results indicate that chlorophyll content is closely related to nutrition and metabolism; with increasing phosphorus content, root activity increased, followed by a decrease. The root activity in treatment 5 plants was significantly higher than that of other treatments. Treatment 1 plants had the lowest root activity, but there was no significant difference in root activity between treatments 6 and 1. Root activity is an important factor that reflects the strength of crop metabolic activity.

Effects of different phosphate levels on lettuce yield and nutritional quality

The effects of different phosphate levels on lettuce yield and nutritional quality are shown in Table 1. With increasing phosphorus content, the yield per plant of lettuce increased initially. When a certain level of phosphorus was applied, the lettuce yield per plant began to decline. In addition, the vitamin C content first increased and then decreased; the vitamin C content of treatment 5 plants was significantly higher than that of the other treatments, and treatment 1 plants had the lowest vitamin C content. With increasing phosphorus application, the protein level decreased, followed by an increase. There was no significant difference in protein level between treatments 4 and 5, but these levels were significantly higher in treatment 4 and 5 than in the other treatments; the vitamin C content in treatment 1 was the lowest. The soluble sugar content first increased gradually, and then slowly declined, in response to increasing phosphorus levels. The soluble sugar content was significantly higher in treatment 4 plants than in the other treatments, while the soluble sugar content of treatment 6 plants was the lowest. The soluble solids content increased, followed by a decrease, in response to increasing phosphorus levels. The soluble solid content in treatment 5 plants was significantly higher than that in the other treatments, while treatment 6 plants had the lowest soluble solids content.

Table 1 Effects of different phosphate levels on lettuce yield and nutritional quality

Treatment	Yield (g·plant ⁻¹)	Vitamin c content [mg·kg ⁻¹]	Protein content [mg·g ⁻¹]	Soluble sugar content[mg·g ⁻¹]	Soluble solids content[%]
1	19.623±0.783Cc	405.11±5.84Dd	40.261±0.637Cd	3.234±0.256Cd	5.182±0.021Cc
2	29.247±2.184ABab	422.27±1.06BCbc	43.903±0.237Cc	4.078±0.061Bc	5.246±0.037Cc
3	31.851±3.234ABab	427.75±5.63BCb	48.213±0.229Bb	4.514±0.171Bb	6.151±0.041Bb
4	36.295±3.931Aa	435.91±5.60Bb	52.437±0.319Aa	5.067±0.104Aa	6.178±0.056Bb
5	33.754±3.481ABa	459.24±5.95Aa	53.677±2.634Aa	4.387±0.74Bb	7.837±0.059Aa
6	24.272±3.441Cc	411.75±0.010CDcd	42.985±1.723Ccd	2.934±0.109Cd	4.345±0.018Dd

Discussion

Food safety is an important issue of widespread concern. Vegetables are some of the most widely consumed foods. With the increasing application of chemical fertilizers, there has been a sharp increase in nitrite and nitrate accumulation in vegetables. Green leafy vegetables are subjected to high levels of fertilization, so these vegetables accumulate high levels of nitrate in vivo, which lowers the nutritional value of the crop¹¹.

Nitrate accumulation and metabolism in leafy vegetables is a complex process; exogenous application of nitrogen is the dominant factor that promotes an increase in nitrate content. With increasing levels of nitrogen application, the accumulation of nitrate content increases with no threshold. Therefore, the primary way to reduce nitrate content is to control the rate of nitrogen application¹². Phosphorus is a nutrient that is required for plant growth and development. Phosphorus promotes nitrogen absorption and assimilation, and phosphorus is also an important part of nitrate reductase (NR) and nitrite reductase (NiR), which participate in NO_3^- restoration and assimilation¹³. In this experiment, with increasing phosphorus content, the nitrate content generally decreased. Treatment 6 (0.5 mmol/L phosphorus) improved the nitrate content, but the nitrate contents in all of the treatments were below the maximum safe levels for leafy vegetables (432 mg/kg)¹⁴, so all of the treatments produced safe, high quality vegetables.

Nitrate reductase (NR) is a key enzyme in the process of plant nitrogen metabolism; NR is the rate-limiting enzyme in this process. Increased NR activity (NRA) can improve the utilization of nitrogen and reduce the nitrate content of vegetables¹⁵. Studies have shown that under soilless cultivation conditions, 7-day-old cucumber seedlings exhibit some tolerance to osmotic stress; the plant growth potential of the plant is not affected by moderate levels of osmotic stress. However, the application of sodium sulfate or PEG causes a 20% decline in both the fresh weight and dry mass of the roots, accompanied by slower cotyledon growth. Salt stress leads to a significant reduction in the nitrate contents of roots and cotyledons, while nitrate reductase activity in roots does not change significantly, and the enzyme activity in cotyledons decreases slightly¹⁶. In the current experiment, the nitrate reductase activity in treatment 4 (0.3 mmol/L) plants was significantly higher than that in the other treatments. In addition, as the phosphorus content increased, the nitrate reductase activity declined, which indicates that high phosphorus levels stress the plants, thereby affecting nitrate reductase activity.

Catalase (CAT), which is ubiquitous in plants, plays a major role in the decomposition of hydrogen peroxide produced in the process of respiration, which helps eliminate damage caused by the accumulation of peroxide¹⁷. Hydrogen peroxide activity is associated with the intensity of plant metabolism as well as stress resistance, which varies with plant variety and at different stages of plant growth¹⁸. In this experiment, catalase activity was the strongest in treatment 5 (0.4 mmol/L) plants, and it declined in treatment 6 (0.5 mmol/L), which indicates that low levels of potassium impact the activity of superoxide dismutase, catalase, peroxidase and the membrane lipid peroxidation of lettuce leaves. When the levels of phosphorus and potassium increased, catalase activity decreased, and phosphorus had a significantly protective effect against free-radical damage.

Ascorbic acid oxidase is widely distributed in plants, which, coupled with other redox agents, functions as a terminal oxidase. Ascorbic acid can be oxidized into monodehydroascorbate. Therefore, the redox state of ascorbic acids can be regulated in vegetables. Ascorbate oxidase plays an important role in plant metabolism¹⁹. In this experiment, treatment 5 (0.4 mmol/L) and treatment 4 (0.3 mmol/L) produced plants with the highest ascorbic acid oxidase activity levels. Under high phosphate conditions, ascorbic acid oxidase enzyme activity declined, producing ion stress effects in the plants.

Chlorophyll content is an important indicator of crop nutrition and growth conditions. Chlorophyll content is closely related to photosynthetic rate, especially during the accumulation of photosynthetic assimilates; chlorophyll content and the photosynthetic intensity of leaves are positively correlated²⁰. At the same time, root activity is an objective physiological indicator²¹. Root absorption vitality reflects the overall performance of root weight, quantity, root water uptake and water delivery; high root absorption vitality indicates that the weight, quantity, water uptake and water delivery of roots are good, which lays the foundation for high yield. In this experiment, the appropriate level of phosphate treatment led to a significant increase in chlorophyll content and root activity, which increased the yield of the lettuce.

In this experiment, the yield per lettuce plant was higher in treatment 4 (0.3 mmol/L) and treatment 5 (0.4 mmol/L) plants than in the other treatments. This trend was also observed for vitamin C content, protein content, soluble sugar content and

soluble solids content. However, high levels of phosphorus treatment led to a decrease in the levels of these indicators. These results are similar to the results of Chesti M H *et al.*²² and Ahmad M *et al.*²³.

In this experiment, we found that treatment 4 (0.3 mmol/L phosphorus) and treatment 5 (0.4 mmol/L phosphorus) led to the production of lettuce plants with lower nitrate content, higher nitrate reductase, catalase and ascorbic acid oxidase activity, higher chlorophyll content, stronger root activity, higher yields and better quality than the other treatments. These phosphate treatment levels are therefore suitable for lettuce production.

Materials And Methods

The lettuce (*Solanum tuberosum* L) seeds, Grand Rapid, were purchased from Horticultural Branch of Heilongjiang Academy of Agriculture Sciences (Harbin, Heilongjiang, China, 150069).

This experiment employed 0.2 × Hoagland’s nutrient solution containing various concentrations of phosphorus, including 0.05, 0.1, 0.2, 0.3, 0.4 and 0.5 mmol/L for treatments 1, 2, 3, 4, 5 and 6, respectively; the other ingredients were not altered. The compositions of the major elements of the nutrient solutions are shown in Table 2, and the trace element composition of the nutrient solution is shown in Table 3.

Table 2 Nutrient solution formula for major elements (Units: mg·L⁻¹)

Treatment	Ca(NO ₃) ₂ ·4H ₂ O	KNO ₃	MgSO ₄ ·7H ₂ O	(NH ₄) ₂ SO ₄	Na ₂ HPO ₄	Na ₂ HPO ₄ ·2H ₂ O
1	189.0	121.4	98.6	19.8	7.1	0
2	189.0	121.4	98.6	19.8	14.2	0
3	189.0	121.4	98.6	19.8	28.4	0
4	189.0	121.4	98.6	19.8	42.6	0
5	189.0	121.4	98.6	19.8	0	48.0
6	189.0	121.4	98.6	19.8	0	71

Table 3 Nutrient solution formula for trace elements (Units: mg·L⁻¹)

Compound Name	Concentration
Na ₂ Fe-EDTA or FeSO ₄ ·7H ₂ O (Na ₂ EDTA)	20 or 27.8/37.2
H ₃ BO ₃	2.86
MnSO ₄ ·4H ₂ O	2.13
ZnSO ₄ ·7H ₂ O	0.22
CuSO ₄ ·5H ₂ O	0.08
(NH ₄) ₆ Mo ₇ O ₂₄ ·4H ₂ O	0.02

For each treatment, twenty seeds were planted in a plastic pot (diameter × height, 29.5 cm × 20 cm) in soil (perlite: peat: vermiculite volume ratio was 1:2:1), with ten pots per treatment; each treatment was repeated five times. Experiments were conducted between 2017 and 2018 in a greenhouse at the Horticulture and Landscape Architecture College of Heilongjiang Bayi Agricultural University’s Experimental Base , Daqing, Heilongjiang, China.

The seeds were disinfected with 0.1% HgCl₂ solution prior to planting. The seeds were sown in plastic pots on May 16, and the seedlings emerged after 3 days. The pots were watered with tap water during for first 5 days of the experiment, after which they were watered with nutrient solution (containing the proper concentration of phosphorus) once per day for 5 days and 1–2 times per day thereafter. The plants were watered at a rate of 1.5 L per pot (to maintain appropriate moisture levels). The plants were harvested 40 days after emergence and subjected to analysis.

All the experiments are conducted in the accordance with the relevant institutional, national, and international guidelines /legislation.

Plant Analysis

Thirty plants of uniform appearance per treatment were randomly selected, washed with distilled water, dried with absorbent paper and weighed using an electronic balance.

The nitrate content of the lettuce was determined spectrophotometrically at 540 nm, and the mg/kg fresh weight was calculated as described by Bian *et al*²⁴. The nitrate reductase activity (NRA) of the plant material was spectrophotometrically determined²⁵. Details about the NRA test are also presented in Arslan and Gülerüz²⁶. Total CAT activity was spectrophotometrically measured using the method of Kato M and Shimizu²⁷. Ascorbic acid oxidase extraction and activity analysis were performed using the method of Pignocchi *et al*²⁸.

The extraction and measurement of chlorophyll were performed as follows: 0.1 g of green leaf tissue was placed in a sample vial containing 25 ml of acetone, which was then sealed; each extraction was performed in triplicate. The chlorophyll extracts were stored in a dark environment for 12 h under ambient conditions or at 4°C. The absorption spectrum of chlorophyll was recorded between 350 and 750 nm at a scan speed of 400 nm/min using an ultraviolet-visible (UV-VIS) spectrophotometer. The chlorophyll content was then calculated using the extinction coefficients and equations of Gratani²⁹. Measurements of root vigor were performed using the triphenyltetrazolium chloride (TTC) method³⁰.

The extraction and measurement of ascorbate (vitamin C) was performed using the standard 2,6 dichlorophenol-indophenol dye method³¹. Soluble proteins were measured by Coomassie brilliant blue method³². The content of soluble sugars was measured by the method of sulfuric acid anthrone³³. Soluble sugars were extracted in 5 mL of boiling 80% (v/v) ethanol for an hour, followed by centrifugation at 10,000 × *g* at 4°C for 10 min. The process was repeated for complete extraction. The amounts of total soluble sugar were determined using anthrone reagent, with glucose as the standard. The soluble solid contents were determined using Abel refractometer direct determination³⁴.

Statistical Analysis

The results obtained in this experiment were subjected to statistical analysis using the SPSS 13.0 statistics program. Multi-way analysis of variance and Duncan's test ($P \leq 0.05$) were applied for the determination of the significance of differences between means. All experiments were performed with three technological replications from two years of investigation, and the results were presented as the mean of all data combined.

Conclusion

Yield and quality have always been the core factors of lettuce production. It is of great significance to study the regulation of nutritional conditions on lettuce production. As an essential nutrient element for crops, phosphorus plays an important role in the growth and development, yield and quality formation of vegetables. The results showed that appropriate phosphorus could increase chlorophyll content and root activity, improve nitrate reductase activity, catalase activity and ascorbic acid oxidase activity, increase quality traits including vitamin C, protein, soluble sugar and soluble solid content, reduce nitrate content and increase yield. These findings provide a better guidance for the production practice of lettuce with high yield, high quality and safety.

References

1. Garcia Ciudad A, *et al*. Effect of fertilization on aerial biomass performance and nitrogen and phosphorous concentrations in rape plants. *Agricultura*, (160):103-107(2009).
2. Wahocho N A, *et al*. Effects of varying nitrogen, phosphorous and potassium doses on the growth, development and yield of radish (*Raphanus sativus* L.). *Pakistan Journal of Agriculture, Agricultural Engineering Veterinary Sciences*, 25(1):22-24(2010).

3. Mikulich V A. Content and removal of nutrients with yield of spring wheat in the conditions of different phosphorous supply of sod-podzolic loamy sandy soil. *PochBoBedehne n agpoxnmnRhaychhbln xyphal*, (1):135-145(2011).
4. Rufty T W, MacKown C T, Israel D W. Phosphorus stress effects on assimilation of nitrate. *Plant Physiology*, 94: 328-333(1990).
5. Geetha V, Kuruvilla V, Varughese K. Response of vegetable cow pea to nitrogen and potassium under varying methods of irrigation. *Journal of Tropical Agriculture*, 39(2): 111-113(2001).
6. Wang X L, Wang Y Q, Tao Y. Ammonium effects on nitrate uptake by roots of upland and Paddy Rice seedlings related to membrane potential differences. *Agricultural Sciences in China* 9(6):799-805(2010).
7. Seo Y H, *et al.* Effect of rice straw and woodchip application on greenhouse soil properties and vegetable crops productivity. *Korean Journal of Soil Science and Fertilizer*, 40(1):4-11(2007).
8. Ju X T, *et al.* Reducing environmental risk by improving N management in intensive Chinese agricultural systems. *Proceedings of the National Academy of Sciences*, 106(9): 3041-3046(2009).
9. Du H X, Wu P, Wang B Q. Influence of applying phosphorus on soil nitrate N and nutrient uptake and yield of summer maize. *Journal of Northwest Agriculture and Forestry University(Natural Science Edition)*, 37(8): 121-126(2009).
10. Magalhaes J V D, *et al.* Nitrate uptake by corn under increasing periods of phosphorus starvation. *Journal of plant nutrition* 21(8): 1753-1763(1998).
11. Boink A & Speijers G. Health effects of nitrates and nitrites. *Acta Horticulturae* 563:29-36(2001).
12. Zhou Z Y, Wang M J, Wang J S. Nitrate and nitrite contamination in vegetables in China. *Food Reviews International* 16:61-76(2000).
13. Sadeghi P M M, Hasan P J, Nasri M. Effect of different levels of nitrogen and phosphorous fertilizers on nitrate accumulation and agronomic characteristics in lettuce[J]. *Pajouhesh And Sazandegi* 21(Special Issue):107-112(2009).
14. Santamaria P. A brief history of nitrate risk in vegetables. *Colture Protette*, 31(12): 4-6(2002).
15. Gan YB, *et al.* Physiological changes in soybean(*Glycine max*) Wuyin in response to N and P nutrition. *Annals of applied biology*, 140(3): 319-329(2002).
16. Turan M & Sezen Y. Nitrate reductase activity in cabbage(*Brassica oleracea* var. *capitata*) seedlings affected by the different nitrogen fertilizer forms. *Acta Agrobotanica*, 57(1/2): 41-48(2004).
17. Sacala E. The influence of osmotic stress on growth and nitrate reductase activity in cucumber seedlings(*Cucumis sativus* L.). *Zeszyty Naukowe Uniwersytetu Przyrodniczego*, 574(95): 75-86(2009).
18. Zamocky M, Furtmüller P G, Obin C. Evolution of catalases from bacteria to humans. *Antioxidants & Redox Signaling*, 10(9): 1527-1548(2008).
19. Sanmartin M, *et al.* Differential expression of the ascorbate oxidase multigene family during fruit development and in response to stress. *Planta*, 225(4): 873-888(2007).
20. Lee C H, *et al.* Effects of light intensity on photosynthesis and growth in seedling of *Kalopanax pictus* Nakai. *Korean Journal of Medicinal Crop Science*, 14:244-249(2006).
21. Li D, *et al.* Effect of continuous negative pressure water supply on the growth, development and physiological mechanism of *Capsicum annuum* L. *Journal of Integrative Agriculture*, 16(9):1978-1989(2017).
22. Cheti M H, Ali T, Bhat M A. Effect of organic and inorganic phosphorus sources on quality of green gram(*Vigna radiata* L.) under temperate conditions of jammu and kashmir. *Legume Research*, 35(1):47-49(2012).
23. Ahmad M, *et al.* Phosphorus application to cotton enhances growth, yield, and quality characteristics on a sandy loam soil. *Pakistan Journal of Agricultural Sciences*, 46(3): 169-173(2009).
24. Bian Z H, *et al.* Continuous light from red, blue, and green light-emitting diodes reduces nitrate content and enhances phytochemical concentrations and antioxidant capacity in lettuce. *Journal of American Society for Horticulture*

Science, 141, 186–195(2016).

25. Hageman R H & Reed A J. Nitrate reductase from higher plants. In: Methods in Enzymology. Elsevier, New York, USA: 270–280(1980).
26. Arslan & Güleriyüz. A study on nitrate reductase activity (NRA) of geophytes from Mediterranean environment. [Flora - Morphology, Distribution, Functional Ecology of Plants](#), 200: 434–443(2005).
27. Kato M & Shimizu S. Chlorophyll metabolism in higher plants. Chlorophyll degradation in senescing tobacco leaves. phenolic-dependent peroxidative degradation. *Can J Bot* 65:729-735(1987).
28. Pignocchi C, *et al.* The function of ascorbate oxidase in tobacco. *Plant Physiology* 132(3):1631-1641(2003).
29. Gratani L. A non-destructive method to determine chlorophyll content of leaves. *Photosynthetica*, 26, 469–473(1992).
30. Luo H H, Zhang Y L, Zhang W F. Effects of water stress and rewatering on photosynthesis, root activity, and yield of cotton with drip irrigation under mulch. *Photosynthetica*, 54, 65–73(2016).
31. Kampfenkel K, Vanmontagu M, Inze D. Extraction and determination of ascorbate and dehydroascorbate from plant tissue. *Analytical Biochemistry*, 225, 165–167(1995).
32. Zheng Y J, *et al.* Supplemental blue light increases growth and quality of greenhouse pak choi depending on cultivar and supplemental light intensity. *Journal of Integrative Agriculture*, 17(10): 2245–2256(2018).
33. Song S, *et al.* Effect of ammonium and nitrate ratio on nutritional quality of flowering Chinese cabbage. *Applied Mechanics and Materials*, 142, 188–192(2011).
34. Bai X H, *et al.* Co-Treatment of EFF and 1-MCP for Enhancing the Shelf-Life and Aroma Volatile Compounds of Oriental Sweet Melons (*Cucumis melo* var. *makuwa* Makino). *Journal of Integrative Agriculture*, 13(1): 217-227(2014).

Figures

Figure 1

Effects of different phosphate levels on nitrate content and nitrate reductase activity of lettuce

Figure 2

Effects of different phosphate levels on catalase and ascorbate oxidase activity of lettuce

Figure 3

Effects of different phosphate levels on chlorophyll content and root activity of lettuce