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Effects of Three Humic Acid Foliar Fertilizers on Quality and Photosynthetic Characteristics of Hawthorn

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Abstract [**Objectives**] To investigate the effects of three foliar fertilizers on photosynthetic characteristics, fruit quality and yield of hawthorn. [**Methods**] Taking hawthorn foliar fertilization as the reference, the photosynthetic rate, transpiration rate, intercellular CO_2 concentration, stomatal conductance and single fruit weight of hawthorn leaves were measured under different concentrations of foliar fertilizer. [**Results**] The results showed that the photosynthetic rate, transpiration rate and stomatal conductance of hawthorn leaves increased significantly, while the intercellular CO_2 concentration decreased. Specifically, the fish protein peptide foliar fertilizer performed best, with net photosynthetic rate and transpiration rate increased by 57.22% and 57.51%, respectively. All the three foliar fertilizers significantly reduced the intercellular CO_2 concentration. In addition, fertilization significantly increased the single fruit weight of hawthorn, and the effect of fermented fulvic acid foliar fertilizer was the most significant, with the highest growth rate of 68.49%. [**Conclusions**] Spraying foliar fertilizer significantly increased the content of Vc, titratable acid, anthocyanin and soluble solids of hawthorn fruit, among which fermented fulvic acid foliar fertilizer had the optimal effect.

Key words Hawthorn, Humic acid, Fulvic acid, Fish protein peptide, Leaf function, Fruit quality

1 Introduction

Photosynthesis is a key process of plant growth and development, and it directly affects the physiological metabolism and energy supply of plants. In recent years, Humic acid foliar fertilizer, fermented fulvic acid foliar fertilizer and fish protein peptide foliar fertilizer[2] play an important role in plant growth regulation, In particular, the regulation mechanism of photosynthesis and fruit quality has attracted wide attention. Studies[3-5] have shown that these three kinds of fertilizers have a significant regulatory effect on plant photosynthesis and fruit quality, thereby affecting plant growth and yield[6]. In this study, taking hawthorn (*Crataegus pinnatifida*) as the research object, we explored the regulation effects of three kinds of foliar fertilizers on photosynthetic rate and fruit quality of hawthorn. The results indicate that they played an significant role in optimizing the growth quality of hawthorn and improving fruit yield. This study is expected to provide a support for scientific fertilization of hawthorn trees.

2 Experiment and methods

2.1 Experimental site The field plot experiment was conducted in Xidaogou Village, Beiyingfang Town, Xinglong County, Chengde City, Hebei Province. The average annual temperature was 6.5 - 10.3 ℃, the lowest temperature was about -7.5 ℃, the frost-free period was about 135 d, the annual precipitation was about 1 232.4 mm, and the annual sunshine duration was about 2 309.8 h.

2.2 Experimental materials The tested crops were hawthorn with good growth as the test materials, with the row spacing of 3 m × 3 m, and planted in the north-south direction. Test fertilizer: Humic acid water-soluble fertilizer was purchased from Jiangsu Longdeng Chemical Co., Ltd. with humic acid ≥40 g/L, $N + P_2O_5 + K_2O \geq 200$ g/L. Fermented fulvic acid water-soluble fertilizer was purchased from Shandong Cangyuan Biotechnology Co., Ltd. with fulvic acid ≥50%, humic acid ≥50%, organic matter ≥60%, potassium oxide 12%. The fish protein peptide foliar fertilizer was purchased from Qingdao Shibaili International Trading Co., Ltd. with fish protein and active peptide ≥310 g/L, free amino acid ≥140 g/L, active enzyme ≥100 g/L, rich in amino acid chelate magnesium, boron, iron, aluminum, copper, manganese and other trace elements.

Test soil: yellow soil and its physical and chemical properties include pH between 6.36 and 8.74, organic matter content between 5% and 10%, total nitrogen content between 0.22% and 0.71%, total phosphorus content between 0.11% and 0.24%, total potassium content between 1.13% and 2.52%.

2.3 Experimental treatment In this study, six treatments were set up for each fertilizer, namely, 0 (CK), 0.5, 1.0, 1.5, 2.0 and 2.5 mg/L, respectively. There were 4 hawthorn plants in each treatment group, and fertilization was set up in three stages:

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April 25 – May 5 in the full blossom stage, June 10 – 20 in the late flowering stage, and July 10 – 20 in the hard core stage. During spraying, branches were selected from the southeast, northeast, southwest and northwest corners of the hawthorn trees, six branches were selected, and the spraying was repeated for three times, and labeling and marking were made. In each treatment, the solution concentration is diluted to the concentration required by the test with clear water and then sprayed, and the front and back sides of the leaves of each plant were sprayed in a uniform and careful manner, and the stems and leaves should become wet but do not flow.

Experiment content: By measuring the net photosynthetic rate (Pn), transpiration rate (E), stomatal conductance (Gs), intercellular CO_2 concentration, soluble solids, titratable acid, Vc and anthocyanin content of hawthorn leaves, the effects of foliar fertilizer spraying were analyzed and compared.

2.4 Determination indicators and methods

2.4.1 Determination of hawthorn fruit quality. Soluble solids content was determined by hand-held refractometer; titratable acid content was determined by sodium hydroxide titration; Vc content was determined by dichlorophenol indophenol solution titration; anthocyanin content was determined by spectrophotometer. The formula for calculating the yield increase rate is: Yield increase rate% = [(Yield in the treated area-Yield in the control area)/Yield in the control area] × 100.

2.4.2 Determination of hawthorn photosynthetic indicators. The portable photosynthesis tester Li-6400 was used to measure the photosynthesis in the field. From 9:00 to 10:00 in the morning of a sunny day in the first ten days of July, the mature top leaves of the compound leaves in the middle of the branches in the middle of the sunny side of the crown were selected. Four standard trees were randomly selected from each treatment, and 10 leaves were selected from each tree. Net photosynthetic rate (Pn), transpiration rate (Tr), stomatal conductance (Gs) and intercellular CO_2 concentration (Ci) were measured.

2.5 Data processing Excel software was used for data collection and processing, and DPS was used for data analysis.

3 Results and analysis

3.1 Effects of three different foliar fertilizers on net photosynthetic rate and transpiration rate of hawthorn leaves Under different fertilization concentrations of humic acid foliar fertilizer, fermented fulvic acid foliar fertilizer and fish protein peptide foliar fertilizer, the net photosynthetic rate of hawthorn leaves was significantly higher than that of CK treatment. It can be seen from Table 1 that the growth of fish protein peptide foliar fertilizer treatment was the most significant, which was 35.10%, 38.21%, 44.01%, 49.32%, and 57.21%, respectively; the growth of fermented fulvic acid foliar fertilizer treatment was the smallest, which was 9.52%, 12.32%, 20.60%, 21.74%, and 28.21%, respectively; the net photosynthetic rate of hawthorn leaves in CK treatment was significantly lower than that in humic acid foliar fertilizer, fermented fulvic acid foliar fertilizer and fish protein peptide foliar fertilizer treatments. Among the three foliar fertilizer treatments, the fish protein peptide foliar fertilizer treatment showed the highest net photosynthetic rate, followed by the humic acid foliar fertilizer treatment, while fermented fulvic acid foliar fertilizer treatment was the lowest. The increasing trend of transpiration rate was similar to that of net photosynthetic rate, which was significantly lower in the CK treatment than in the three foliar fertilizer treatments. Considering the data of net photosynthetic rate and transpiration rate, humic acid foliar fertilizer, the treatment effects of fermented fulvic acid foliar fertilizer and fish protein peptide foliar fertilizer are as follows: fish protein peptide foliar fertilizer > humic acid foliar fertilizer > fermented fulvic acid foliar fertilizer > CK. These results emphasized the significant effects of different foliar fertilizers on the physiological characteristics of hawthorn leaves.

Table 1 Effects of three different foliar fertilizers on net photosynthetic rate and transpiration rate of hawthorn leaves

Fertilizer	Fertilization concentration mg/L	Net photosynthetic rate μmol/(m² · sec)	Transpiration rate mmol/(m² · sec)
Humic acid foliar fertilizer	CK	9.63 ± 0.20 e	3.10 ± 0.20 d
	0.5	10.63 ± 0.20 d	4.11 ± 0.20 c
	1	10.94 ± 0.30 c	4.12 ± 0.06 b
	1.5	11.79 ± 0.40 b	4.34 ± 0.01 b
	2	12.02 ± 0.30 b	4.41 ± 0.03 c
	2.5	12.78 ± 0.20 a	4.58 ± 0.03 c
Fermented fulvic acid foliar fertilizer	CK	11.53 ± 0.20 d	7.00 ± 0.20 d
	0.5	12.63 ± 0.20 c	8.10 ± 0.20 c
	1	12.95 ± 0.30 c	8.12 ± 0.06 c
	1.5	13.90 ± 0.60 b	8.34 ± 0.01 b
	2	14.03 ± 0.30 b	8.40 ± 0.03 b
	2.5	14.78 ± 0.20 a	8.58 ± 0.03 a
Fish protein peptide foliar fertilizer	CK	9.72 ± 0.20 d	4.50 ± 0.30 d
	0.5	13.13 ± 0.20 c	6.59 ± 0.20 c
	1	13.44 ± 0.30 c	6.62 ± 0.06 c
	1.5	14.39 ± 0.60 b	6.84 ± 0.01 b
	2	14.51 ± 0.60 b	6.85 ± 0.02 b
	2.5	15.28 ± 0.20 a	7.09 ± 0.04 a

NOTE Data in the same column followed by the same lowercase letter indicate that the difference between treatments is not significant ($P < 0.05$), the same below.

3.2 Effects of three different foliar fertilizers on stomatal conductance and intercellular CO_2 concentration of hawthorn leaves The effects of different fertilizers on stomatal conductance of hawthorn leaves were different. Under different fertilization concentrations of humic acid foliar fertilizer, fermented fulvic acid foliar fertilizer and fish protein peptide foliar fertilizer, the stomatal conductance of hawthorn leaves showed an upward trend with the increase of treatment concentration (Table 2). Compared with CK treatment, humic acid foliar fertilizer, the stomatal conductance values of fermented fulvic acid foliar fertilizer and fish protein peptide foliar fertilizer were significantly increased under different fer-

tilization concentrations. Among them, the increase of fermented fulvic acid foliar fertilizer treatment was the most significant, which was 16.43%, 17.51%, 34.03%, 39.10%, and 48.45%, respectively. The increase of humic acid foliar fertilizer was relatively small, which was 25.01%, 37.54%, 50.01%, 62.52%, and 75.23%, respectively. Among the three foliar fertilizer treatments, the fermented fulvic acid foliar fertilizer treatment showed the highest stomatal conductance, followed by the fish protein peptide foliar fertilizer treatment, and that humic acid foliar fertilizer treatment was the lowest. The results of comprehensive data analysis were as follows: the treatment effects of humic acid foliar fertilizer, fermented fulvic acid foliar fertilizer and fish protein peptide foliar fertilizer were as follows: fermented fulvic acid foliar fertilizer > fish protein peptide foliar fertilizer > humic acid foliar fertilizer > CK. Under different foliar fertilizer treatments, the intercellular CO_2 concentration of hawthorn leaves showed a decreasing trend with the increase of treatment concentration. As can be seen from table 2, under different fertilization concentrations of humic acid foliar fertilizer, fermented fulvic acid foliar fertilizer and fish protein peptide foliar fertilizer, the intercellular CO_2 concentration values of the three foliar fertilizers all showed a downward trend. Among them, the effect of fish protein peptide foliar fertilizer treatment was the most significant, which was 2.42%, 3.34%, 3.65%, 5.36%, and 6.21%, respectively; the decrease of humic acid foliar fertilizer was relatively small, 1.22%, 1.31%, 2.02%, 2.23%, and 2.45%, respectively. Therefore, the effects of three foliar fertilizers on intercellular CO_2 concentration of hawthorn leaves were fish protein peptide foliar fertilizer > fermented fulvic acid foliar fertilizer > humic acid foliar fertilizer > CK.

Table 2 Effects of three different foliar fertilizers on stomatal conductance and intercellular CO_2 concentration of hawthorn leaves

Fertilizer	Fertilization concentration mg/L	Stomatal conductance mmol/(m^2 · sec)	Intercellular CO_2 concentration μmol/(m^2 · sec)
Humic acid foliar fertilizer	CK	0.08 ± 0.02 c	288.81 ± 0.70 a
	0.5	0.10 ± 0.01 bc	285.23 ± 0.80 b
	1	0.11 ± 0.01 b	284.79 ± 0.80 b
	1.5	0.12 ± 0.03 ab	282.89 ± 0.50 c
	2	0.13 ± 0.05 a	282.23 ± 0.60 cd
	2.5	0.14 ± 0.03 ab	281.86 ± 0.40 d
Fermented fulvic acid foliar fertilizer	CK	0.09 ± 0.01 e	293.38 ± 0.50 a
	0.5	0.11 ± 0.01 d	286.76 ± 0.40 b
	1	0.11 ± 0.01 d	284.65 ± 0.20 c
	1.5	0.13 ± 0.01 c	282.23 ± 0.40 d
	2	0.13 ± 0.01 b	278.49 ± 0.30 e
	2.5	0.14 ± 0.01 a	275.39 ± 0.20 e
Fish protein peptide foliar fertilizer	CK	0.08 ± 0.02 c	292.78 ± 1.11 a
	0.5	0.12 ± 0.01 bc	285.49 ± 1.58 ab
	1	0.12 ± 0.01 bc	283.00 ± 1.91 b
	1.5	0.13 ± 0.01 ab	281.98 ± 5.97 c
	2	0.14 ± 0.01 a	277.19 ± 8.49 d
	2.5	0.14 ± 0.01 a	274.59 ± 9.61 d

3.3 Effects of three different foliar fertilizers on single fruit weight and yield of hawthorn Different foliar fertilizers had different effects on the single fruit weight of hawthorn. The single fruit weight of hawthorn increased with the increase of treatment concentration under three different fertilizer treatments. As can be seen from Table 3, under different fertilization concentrations of humic acid foliar fertilizer, fermented fulvic acid foliar fertilizer and fish protein peptide foliar fertilizer, the single fruit weight of hawthorn was significantly higher than that of CK treatment. Specifically, the increase of fermented fulvic acid foliar fertilizer treatment was the most significantly, which was 15.33%, 15.44%, 41.65%, 44.87%, and 68.49%, respectively. The increase of humic acid foliar fertilizer was the smallest, which was 20.69%, 21.39%, 42.23%, 43.21%, and 58.88%, respectively. The single fruit weight of hawthorn in CK treatment was significantly lower than that in humic acid foliar fertilizer, fermented fulvic acid foliar fertilizer and fish protein peptide foliar fertilizer treatments. In the three foliar fertilizer treatments, the maximum single fruit weight of fermented fulvic acid foliar fertilizer treatment was 16.26 g, the maximum single fruit weight of fish protein peptide foliar fertilizer treatment was 12.36 g, while the maximum single fruit weight of humic acid foliar fertilizer treatment was 11.36 g. The analysis results of humic acid foliar fertilizer, fermented fulvic acid foliar fertilizer, and fish protein peptide foliar fertilizer were: fermented fulvic acid foliar fertilizer > fish protein peptide foliar fertilizer > humic acid foliar fertilizer > CK. In addition, with the increase of treatment concentration, the yield increase rate of the three foliar fertilizers showed an upward trend. Among them, fermented fulvic acid foliar fertilizer showed the highest yield in-

Table 3 Effects of three different foliar fertilizers on single fruit weight and yield of hawthorn

Fertilizer	Fertilization concentration mg/L	Single fruit weight//g	Yield per plant//kg	Yield increase rate//%
Humic acid foliar fertilizer	CK	7.15 ± 0.01 d	30.26 ± 0.30 d	–
	0.5	8.63 ± 0.09 c	32.21 ± 1.10 b	7.37
	1	8.68 ± 0.05 c	32.11 ± 0.80 b	7.03
	1.5	10.17 ± 0.05 b	32.40 ± 0.80 b	8.00
	2	10.24 ± 0.05 b	36.91 ± 0.60 a	23.03
	2.5	11.36 ± 0.03 a	36.94 ± 0.50 a	23.13
Fermented fulvic acid foliar fertilizer	CK	9.65 ± 0.01 d	30.57 ± 0.40 d	–
	0.5	11.13 ± 0.09 c	32.92 ± 0.70 c	9.73
	1	11.14 ± 0.09 c	35.86 ± 0.60 b	19.53
	1.5	13.67 ± 0.03 b	35.93 ± 0.60 b	19.76
	2	13.98 ± 0.03 b	38.99 ± 0.50 a	29.96
	2.5	16.26 ± 0.05 a	39.01 ± 0.40 a	30.03
Fish protein peptide foliar fertilizer	CK	9.45 ± 0.01 e	30.89 ± 0.80 d	–
	0.5	10.63 ± 0.09 d	34.11 ± 0.70 c	13.70
	1	10.72 ± 0.09 d	37.91 ± 0.50 b	26.37
	1.5	11.16 ± 0.03 c	37.94 ± 0.60 b	26.47
	2	11.26 ± 0.01 b	40.97 ± 0.50 a	36.57
	2.5	12.36 ± 0.03 a	41.02 ± 0.60 a	36.73

crease rate in the concentration range of 0.5 – 2.5 mg/L, which was 9.73%, 19.53%, 19.76%, 29.96%, and 30.03%, respectively. The second was fish protein peptide foliar fertilizer, and the increasing rates were 13.7%, 26.37%, 26.47%, 36.57%, and 36.73% respectively. The yields of humic acid foliar fertilizer were relatively low, which was 7.37%, 7.03%, 8.00%, 23.03% and 23.13%, respectively. The results of data analysis showed that fermented fulvic acid foliar fertilizer had the best effect in increasing the hawthorn yield.

3.4 Effects of three different foliar fertilizers on fruit quality of hawthorn It can be seen from Table 4 that the spraying of foliar fertilizer significantly increased the contents of soluble solids, titratable acid, Vc and anthocyanin in hawthorn fruit. Fermented fulvic acid foliar fertilizer treatment had the most significant effect on these indicators, followed by fish protein peptide foliar fertilizer, while the effect of increasing humic acid foliar fertilizer was limited. The fruit indicators of the three foliar fertilizer treatments were significantly higher than those of the control CK. Among them, the fermented fulvic acid foliar fertilizer showed the best performance in terms of Vc, with the highest growth rate of 6.63%, while the humic acid foliar fertilizer showed the lowest Vc growth rate of 12.80%. In terms of titratable acidity, fermented fulvic acid foliar fertilizer treatment increased the most by 32.72%, while humic acid foliar fertilizer increased the most by 24.02%. For anthocyanin and soluble solids, the effect of fermented fulvic acid foliar fertilizer treatment was the most significant, with the maximum increase of 40.97% and 44.31%, respectively. The treatment effect of humic acid foliar fertilizer was relatively weak, and the growth rates were 35.02% and 37.66%, respectively. The analysis results indicate that fermented fulvic acid foliar fertilizer > fish protein peptide foliar fertilizer > humic acid foliar fertilizer > CK, reflecting significant effects of different foliar fertilizers on fruit quality of hawthorn.

Table 4 Effects of three different foliar fertilizers on fruit quality of hawthorn

Fertilizer	Fertilization concentration//mg/L	Soluble solids//%	Titratable acid//%	Vc//mg/100 g	Anthocyanin mg/(g·FW)
humic acid foliar fertilizer	CK	3.85 ±0.40 b	12.82 ±0.14 c	83.40 ±0.30 d	3.54 ±0.02 e
	0.5	4.10 ±0.16 b	13.34 ±0.11 c	85.33 ±0.10 c	3.84 ±0.01 d
	1	4.30 ±0.73 b	14.66 ±0.10 b	88.60 ±0.10 b	4.25 ±0.03 c
	1.5	4.45 ±0.05 ab	14.88 ±0.05 b	88.88 ±0.06 b	4.66 ±0.01 b
	2	4.70 ±0.34 ab	15.07 ±0.90 b	93.76 ±0.60 a	4.75 ±0.01 a
	2.5	5.30 ±0.56 a	15.90 ±0.05 a	94.08 ±0.50 a	4.78 ±0.03 a
Fermented fulvic acid foliar fertilizer	CK	6.07 ±0.35 b	14.24 ±0.15 d	92.72 ±0.20 e	5.15 ±0.02 e
	0.5	6.61 ±0.17 b	15.66 ±0.42 c	94.82 ±0.09 d	5.74 ±0.01 d
	1	6.71 ±0.64 ab	16.63 ±0.05 b	95.68 ±0.05 c	5.79 ±0.01 c
	1.5	6.98 ±0.09 ab	16.88 ±0.06 b	95.90 ±0.07 b	6.87 ±0.01 b
	2	8.68 ±0.56 ab	18.79 ±0.06 a	98.76 ±0.07 a	6.89 ±0.03 b
	2.5	8.76 ±0.42 a	18.90 ±0.06 a	98.87 ±0.09 a	7.26 ±0.03 a
Fish protein peptide foliar fertilizer	CK	5.87 ±0.35 b	14.12 ±0.14 d	91.72 ±0.20 e	5.07 ±0.01 e
	0.5	6.12 ±0.17 b	15.45 ±0.39 c	93.74 ±0.08 d	5.68 ±0.01 d
	1	6.35 ±0.74 ab	16.58 ±0.04 b	94.23 ±0.04 c	5.74 ±0.01 c
	1.5	6.47 ±0.09 ab	16.77 ±0.05 b	94.16 ±0.06 b	6.79 ±0.01 b
	2	6.72 ±0.34 ab	18.75 ±0.04 a	97.65 ±0.06 a	6.82 ±0.02 b
	2.5	7.32 ±0.61 a	18.83 ±0.05 a	97.86 ±0.08 a	7.12 ±0.03 a

4 Discussion

(i) Plant leaves play an important role in photosynthesis and transpiration, and regulate plant metabolism[7]. The study of photosynthesis is essential for the advancement of agricultural science and the discipline of sustainable development[8]. Taking *Ginkgo biloba* as an example[9], it was found that foliar fertilization significantly increased photosynthetic rate and stomatal conductance, while reducing transpiration rate and affecting water use efficiency. Another study[10] has also confirmed that different types of foliar fertilizers have a positive effect on the photosynthetic characteristics of plants. For example, spraying humic acid helps to improve the photosynthesis of poplar, and spraying different types of foliar fertilizers also has a significant impact on the photosynthetic characteristics of *Juglans regia*[11], *Cymbidium huxueense*[12], *Abelmoschus esculentus* (L.) Moench[13], Fuji apple[14] and other plants, improving the net photosynthetic rate, reducing the transpiration rate and intercellular CO_2 concentration, and improving the water use efficiency, which is consistent with the results of the present study.

(ii) It is of great significance to compare the quality of hawthorn from the perspective of nutrition. The research results[15] showed that the transverse diameter and single fruit weight of hawthorn fruit increased significantly after spraying foliar fertilizers with different treatments. The fermented fulvic acid foliar fertilizer significantly improved the quality of cabbage[16], and the contents of Vc and soluble solids were significantly higher than those of the control group. Fish protein peptide foliar fertilizer increased the

content of Vc and anthocyanin in fruit. Humic acid foliar fertilizer significantly improved the Vc and titratable acid content of capsicum[17] at suitable concentrations, while increasing the yield. Spraying amino acid foliar fertilizer significantly improved the quality of winter jujube in greenhouse[18], and increased the single fruit weight, vertical and horizontal diameter of fruit and sugar content. Foliar spraying promoted the vegetative growth of trees, increased the mineral nutrient content of leaves, improved the quality of fruits, and effectively inhibited the occurrence of diseases. The results of these studies are consistent with our experimental results, proving that foliar fertilizer has a significant effect on improving fruit quality.

5 Conclusions

In this study, the effects of three foliar fertilizers on photosynthetic characteristics of hawthorn leaves and nutrient contents of hawthorn fruits were compared. The results showed that fermented fulvic acid foliar fertilizer had the most significant promoting effect on hawthorn, which could improve photosynthesis and mineral element accumulation in leaves, and also increase fruit size, weight and nutrient content. The effect of fish protein peptide foliar fertilizer was the second, and the effect of humic acid foliar fertilizer was the least, but the three treatments were better than CK treatment. Therefore, foliar fertilizer should be reasonably selected according to the demand in hawthorn production.

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