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Hormone Metabolism and Substance Accumulation in Cucumber Plants: Downy Mildew Infection and Potassium Stress

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Abstract: In order to understand the effects of biotic stress and abiotic stress on hormone metabolism and substance accumulation in cucumber, two different infection levels of downy mildew were set, B0 (diseased) and B1 (disease-free), and T1 (K-50%: 50% of normal potassium application), T2 (K-100%: normal potassium application), and T3 (K-150%: 150% of normal potassium application). The results show that the hormone metabolism in the cucumber plants was measured on the 15th day after transplanting. Compared with the B1T2 treatment, the cane sugar contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 35.87%, 23.29%, 25.41%, 12.98%, and 6.05%; the soluble sugar contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 36.16%, 27.13%, 31.97%, 9.89%, and 7.84%; the hydrogen peroxide (H_2O_2) contents in the B0T1, B0T2, B0T3, and B1T1 treatments increased by 30.59%, 21.08%, 14.74%, and 9.2%; the catalase (CAT) contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 53.78%, 36.57%, 47.18%, 34.75%, and 16.39%; the superoxide dismutase (SOD) contents in the B0T1, B0T2, B0T3, and B1T1 treatments increased by 30.28%, 22.59%, 12.9%, and 13.17%; and the polyphenol oxidase (PPO) contents in the B0T1, B0T2, B0T3, and B1T1 treatments increased by 39.38%, 25.27%, 4.49%, and 23.05%, respectively. Compared with the B1T2 treatment, the malondialdehyde (MDA) contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments increased by 82.78%, 23.07%, 60.21%, 74.55%, and 25.12%. Compared with the B1T2 treatment, the hydrogen peroxide (H_2O_2), superoxide dismutase (SOD), and polyphenol oxidase (PPO) contents in the B1T3 treatment decreased by 16.11%, 4.36%, and 4.43%. On the 20th day after transplanting the cucumber plants, downy mildew infection and potassium stress had significant effects on the dry and fresh weights of the leaves, stems, and roots ($p < 0.05$). The B0T1 treatment had the greatest effect on the dry and fresh weights of the leaves, stems, and roots of the cucumber plants. The B1T3 treatment had the least effect on the dry and fresh weights of the leaves, stems, and roots of the cucumber plants. This research can provide a theoretical basis for the study and cultivation of cucumber stress resistance.

Keywords: *Cucumis sativus* L.; biological stress; abiotic stress; physiological metabolism

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1. Introduction

The protected cultivation area in China is more than 4.2 million hectares, and it is widely distributed in China, ranking first in the world in total area [1,2]. It is the main

support of China's vegetable basket project and one of the important ways to increase farmers' incomes [3,4]. Cucumber is deeply loved by consumers because of its rich taste and nutritional value, and the cucumber cultivation area accounts for the main part of the protected cultivation area in China [5,6]. Cucumber is inevitably exposed to abiotic stress (such as salt stress, drought stress, high-temperature stress, low-temperature stress, and UV-B stress) and biological stress (such as bacterial diseases and fungal diseases) during its growth [7–9]. Therefore, it is particularly important to understand its stress response and adaptation mechanism under different stresses and be effective in preventing greenhouse airborne diseases in time [10–12].

Cucumber downy mildew is caused by *Pseudoperonospora cubensis* infection. After the disease occurs, it mainly harms the leaves of cucumber plants, but also the stems and inflorescences of cucumber plants [1,4]. It can occur from the seedling stage to the growth stage of cucumbers, especially when cucumbers enter the harvest stage. After the disease occurs, most of the leaves of cucumber plants will die within one or two weeks, and the cucumber field will be yellow [13,14]. Cucumber downy mildew will increase year by year with the expansion of the cultivation area and the increase in the years of continuous cropping, which can seriously reduce production, with a yield loss of 20–50% or even no harvest [15,16].

Potassium fertilizer, as a major element for plant growth, is very important for plant growth and development. In the physiological and biochemical reaction network of plants, potassium participates in a variety of processes [17,18]. Potassium ions are needed as an auxiliary factor in enzyme activation to give full play to enzyme activity, thus promoting various chemical reactions to be carried out efficiently. Photosynthesis is the key pathway for plants to convert light energy into chemical energy, in which potassium affects the normal operation of photosynthetic institutions, and the absorption, transmission, and transformation of light energy are inseparable from the role of potassium [19,20]. Respiration is an important way for plants to obtain energy, and potassium also participates in it to ensure smooth respiration and metabolism. In carbohydrate metabolism, potassium plays an indispensable regulatory role in the synthesis, transportation, and transformation of carbohydrates. During the synthesis of proteins, potassium helps to maintain the charge balance in cells, promotes the transport and integration of amino acids, and provides a suitable environment for the synthesis of proteins [21,22]. At the same time, potassium plays a central role in maintaining the osmotic pressure of plant cells. By adjusting the concentration of potassium ions in cells, the normal swelling pressure of cells is ensured, and the morphological and functional stability of plant cells is ensured. In the process of regulating the opening and closing of stomata, the transmembrane transport of potassium ions promotes the guard cells to absorb or lose water, thus controlling the opening and closing of stomata, which is very important for gas exchange and water balance between plants and the external environment [23,24]. Moreover, an adequate potassium supply can significantly enhance the stress resistance of plants. Whether dealing with abiotic stresses, such as drought, flood, high temperature, and low temperature, or resisting biotic stresses, such as pests and diseases, potassium can help plants improve their self-defense ability [25,26].

However, there are relatively few studies on the effects of biotic and abiotic stresses on hormone metabolism and substance accumulation in cucumber plants, and a systematic understanding has not yet been formed [15,27]. Therefore, considering the effects of downy mildew infection and potassium stress on hormone metabolism and substance accumulation in cucumber plants can provide a theoretical basis for the research and cultivation of cucumber stress resistance.

2. Materials and Methods

2.1. Study Site and Experimental Design

The experiment was carried out in the Venlo-type greenhouse of Jiangsu University. The experimental cucumber variety was "Jinyou No.1", selected by the Tianjin Academy of Agricultural Sciences. The experiment started on 25 July 2024 and ended on 18 August 2024. On 29 July 2024, perlite was poured into a flowerpot with a volume of 10 L, and the dust in the perlite was rinsed with tap water. On 30 July 2024, the well-grown and similar cucumber seedlings with two leaves and one heart were taken out of the pot and transplanted. The greenhouse temperature range during the experiment was 16.83~36.47 °C. The temperature range during the day was 20.52~36.47 °C. The average temperature was 25.8 °C. The average relative humidity was 85.6% RH (23.7~95.6% RH). The experimental design consisted of 6 treatments, each of which was repeated 6 times. B0 (diseased) and B1 (disease-free), and T1 (K-50%: 50% of normal potassium application), T2 (K-100%: normal potassium application), and T3 (K-150%: 150% of normal potassium application). Therefore, the six test treatments were B0T1, B0T2, B0T3, B1T1, B1T2, and B1T3. Infected cucumber plants and uninfected cucumber plants were cultivated in different greenhouses. The plant spacing for cucumber cultivation was 50 cm, the row spacing was 32 cm, and the ridge spacing was 60 cm.

The trial treatment began on 6 August 2024. The prepared suspension of pathogenic bacterial spores was sprayed on the cucumber leaves with a spray bottle from 6:00 to 7:00 p.m. The control group was tested by spraying sterile water. The cucumber downy mildew disease degrees were classified according to GB/T179800.26-2000 [28]. In addition, during the experimental treatment period, 400 mL of a nutrient solution was poured into the experimental cucumber plant samples from 8:00 to 9:00 a.m. every day. The dosages of KNO_3 and $NaNO_3$ in the K-50% test treatment were 303 g and 255 g, respectively. The dosage of KNO_3 in the K-100% and K-150% test treatments was 606 g. The dosage of KCl in the K-150% test treatment was 223 g. The usage of elements in other nutrient solutions is detailed in reference [15].

2.2. Experimental Data Acquisition

On the 15th day after transplanting, the hormone metabolism was determined (the disease degree of the cucumber plants was grade 3). The classification of disease severity was based on reference [28]. The content of malondialdehyde (MDA) in the cucumber leaves was determined by the TBA method. The superoxide dismutase (SOD) content in the cucumber leaves was determined by the cytochrome C reduction method. The content of hydrogen peroxide and catalase (CAT) in the cucumber leaves was determined by ammonium molybdate colorimetry. The activity of polyphenol oxidase (PPO) is often determined by spectrophotometry. The measuring principle is that the product formed by the oxidation of catechol, catalyzed by PPO, has a maximum light absorption peak at 420 nm. The soluble sugar content in the cucumber leaves was determined by anthrone colorimetry. Based on the color reaction of sucrose hydrolysate and resorcinol under acidic conditions, the sucrose content in the cucumber leaves was determined at a 480 nm wavelength [29]. The kits for the determination of the malondialdehyde (MDA), superoxide dismutase (SOD), hydrogen peroxide (H_2O_2), catalase (CAT), polyphenol oxidase (PPO), and soluble sugar contents in the cucumber leaves were purchased from the Chengjian Institute of Bioengineering. The determination kit for the sucrose content in the cucumber leaves was purchased from Beijing Suoleibao Technology Co., Ltd. The test equipment was a 721 Visible Spectrophotometer (Shanghai Youke Instrument Co., Ltd. Shanghai, China).

On the last day of the experiment, the leaves, stems, and roots of the cucumber plants were collected, and the fresh weights of the leaves and stems were measured by

an electronic scale (accuracy: 0.01 g). In order to reduce the experimental error, before the measurement of the accumulation of fresh material at the roots, the excess water on the surfaces of the roots was absorbed with absorbent paper, weighed with a precision electronic scale (accuracy: 0.001 g), and then put into an envelope after measurement. After measuring the accumulation of fresh materials in the leaves, stems, and roots of the cucumber plants, they were placed in an oven, and the temperature of the oven was set at 105 °C and kept at a constant temperature for 15 min. Then, the temperature of the oven was set at 80 °C, and the leaves, stems, and roots of the cucumber plants continued to be dried and dried until their weight was constant [16]. At last, the dry weights of the cucumber leaves, stems, and roots were measured by a precision electronic scale (accuracy 0.001 g).

2.3. Statistical Analyses

The statistical analysis software SPSS_29.0.2.0 was used to analyze the data. ANOVA was used to analyze the statistical differences between the two groups. The minimum significant difference (LSD) test was used to determine the level of significance ($p < 0.05$).

3. Results

3.1. Hormone Metabolism

The effects of the different experimental treatments on hormone metabolism in the cucumber plants are shown in Table 1. Downy mildew infection and potassium stress had significant effects on the sucrose and soluble sugar contents in the cucumber leaves ($p < 0.05$). Compared with the B1T2 treatment, the cane sugar contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 35.87%, 23.29%, 25.41%, 12.98%, and 6.05%; the soluble sugar contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 36.16%, 27.13%, 31.97%, 9.89%, and 7.84%; the hydrogen peroxide (H_2O_2) contents in the B0T1, B0T2, B0T3, and B1T1 treatments increased by 30.59%, 21.08%, 14.74%, and 9.2%; the catalase (CAT) contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 53.78%, 36.57%, 47.18%, 34.75%, and 16.39%; the superoxide dismutase (SOD) contents in the B0T1, B0T2, B0T3, and B1T1 treatments increased by 30.28%, 22.59%, 12.9%, and 13.17%; the polyphenol oxidase (PPO) contents in the B0T1, B0T2, B0T3, and B1T1 treatments increased by 39.38%, 25.27%, 4.49%, and 23.05%; and the malondialdehyde (MDA) contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments increased by 82.78%, 23.07%, 60.21%, 74.55%, and 25.12%. Downy mildew infection and potassium stress had significant effects on the hydrogen peroxide (H_2O_2), catalase (CAT), superoxide dismutase (SOD), polyphenol oxidase (PPO), and malondialdehyde (MDA) contents in the cucumber leaves ($p < 0.05$). The hydrogen peroxide (H_2O_2) content in the cucumber leaves treated with B1T3 decreased by 16.11%. The superoxide dismutase (SOD) content in the cucumber leaves treated with B1T3 decreased by 4.36%. The levels of polyphenol oxidase (PPO) in the cucumber leaves treated with B1T3 decreased by 4.43%.

Table 1. Effects of different experimental treatments on metabolic data of cucumber plants.

Treatment	Measurement Index						
	Cane Sugar (mg/gFW)	Soluble Sugar (μg/gFW)	H_2O_2 (mmol/gprot)	CAT (U/mgprot)	SOD (U/gFW)	PPO (U/gFW)	MDA (nmol/mgprot)
B0T1	2.27 ± 0.24f	2794.81 ± 32.02f	4.31 ± 0.67a	7.26 ± 0.43e	686.54 ± 13.91a	109.59 ± 5.39a	1.45 ± 0.21a
B0T2	2.73 ± 0.23d	3190.36 ± 70.26d	3.99 ± 0.35b	9.97 ± 0.32c	646.06 ± 13.11b	98.47 ± 7.73b	0.97 ± 0.13d
B0T3	2.65 ± 0.21e	2978.24 ± 52.5e	3.78 ± 0.46c	8.31 ± 0.19d	595.43 ± 20.63c	82.15 ± 6.19c	1.27 ± 0.11c
B1T1	3.09 ± 0.14c	3507.15 ± 44.92c	3.6 ± 0.43c	10.25 ± 0.13c	596.4 ± 12.14c	96.75 ± 4.41b	1.38 ± 0.16b
B1T2	3.55 ± 0.24a	4377.81 ± 61.19a	3.29 ± 0.36d	15.72 ± 0.23a	526.97 ± 20.03d	78.62 ± 5.2c	0.79 ± 0.13e
B1T3	3.34 ± 0.28b	4034.57 ± 53.34b	3.76 ± 0.23e	13.14 ± 0.38b	503.86 ± 18.94e	75.13 ± 4.39d	0.99 ± 0.15d

Note: Different lowercase letters between treatments indicating significant differences at $p < 0.05$.

3.2. Substance Accumulation

The effects of the different experimental treatments on substance accumulation in the cucumber plants are shown in Figure 1. The dry and fresh weights of the cucumber leaves, the dry and fresh stem weights, and the dry and fresh root weights were significantly affected by the different potassium treatments and downy mildew infection. Compared with the B1T2 treatment, the fresh leaf weight contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 58.13%, 25.39%, 41.29%, 15.49%, and 7.62%; the dry leaf weight contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 53.63%, 43.37%, 48.29%, 25.75%, and 25.48%; the fresh stem weight contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 57.19%, 18.2%, 32.75%, 13.59%, and 4.62%; the dry stem weight contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 27.52%, 13.74%, 15.54%, 10.85%, and 6.46%; the fresh root weight contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 40.06%, 22.18%, 27.94%, 32.96%, and 10.03%; and the dry root weight contents in the B0T1, B0T2, B0T3, B1T1, and B1T3 treatments decreased by 33.14%, 21.54%, 24.63%, 31.92%, and 18.83%.

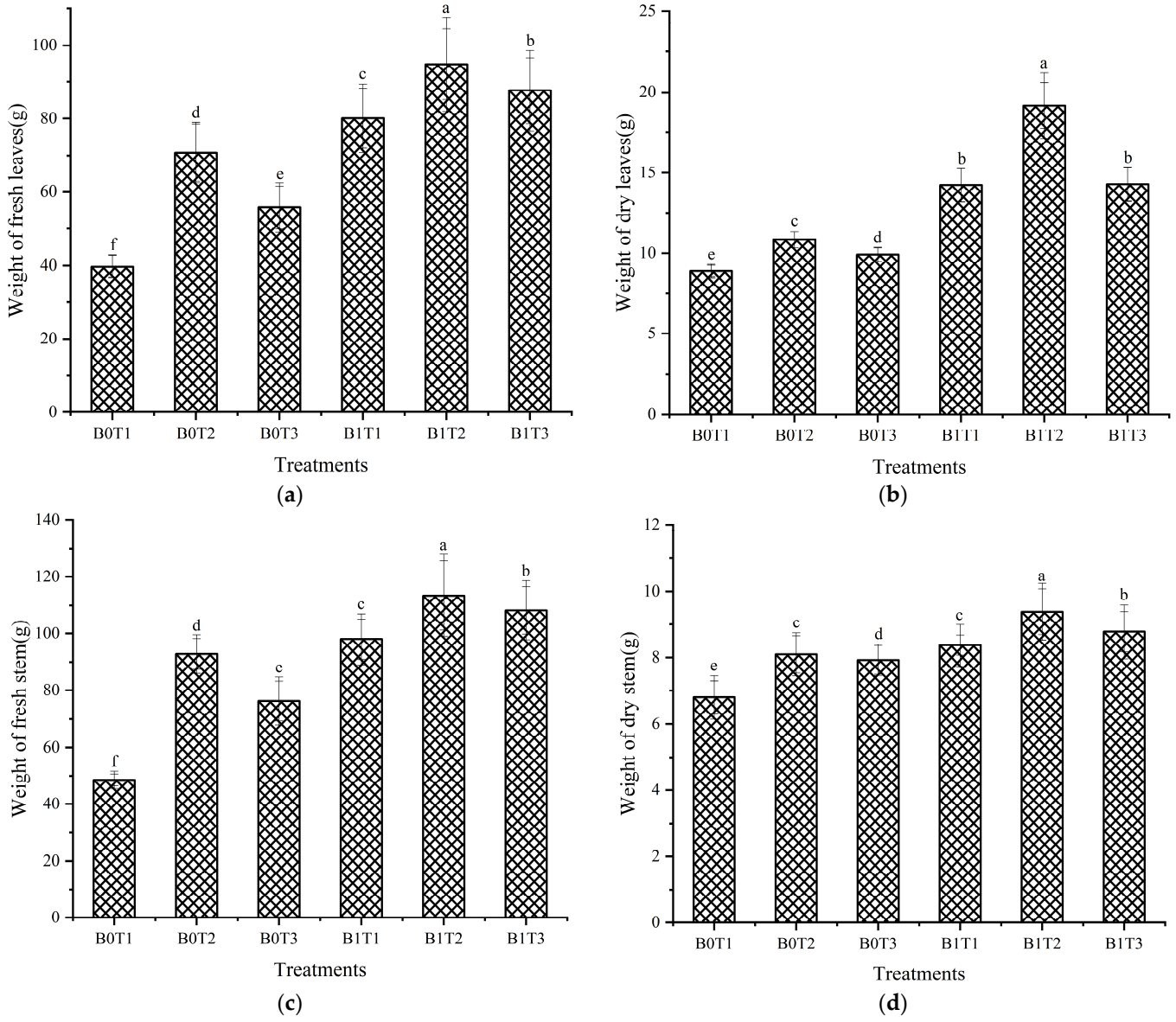

Figure 1. *Cont.*

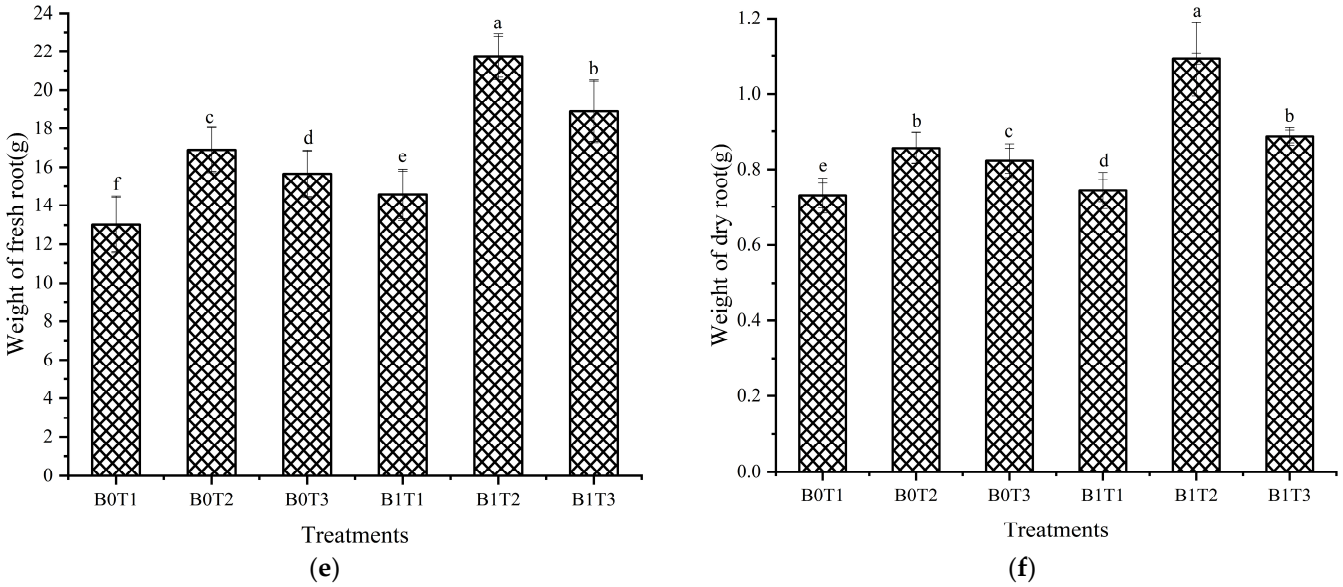

Figure 1. Effects of downy mildew infection and potassium stress on substance accumulation in cucumber plants. Note: Error bars indicate standard deviations, with different lowercase letters between treatments indicating significant differences at $p < 0.05$. (**a**) Weight of fresh leaves; (**b**) weight of dry leaves; (**c**) weight of fresh stems; (**d**) weight of dry stems; (**e**) weight of fresh roots; (**f**) weight of dry roots.

4. Discussion

4.1. Cane Sugar and Soluble Sugar

Downy mildew destroys chloroplasts and other organelles in leaves and affects normal photosynthesis. Photosynthesis is the basis for the synthesis of sugar substances such as sucrose. A decrease in photosynthetic capacity leads to a decrease in the synthesis of photosynthetic products, and the synthesized amount of sucrose also decreases [30,31]. When cucumber plants resist downy mildew infection, they initiate a series of defense reactions, which require a lot of energy. Sucrose, as an important energy source, is decomposed and utilized in priority, resulting in a further reduction in its content in the plant. Sufficient potassium can promote photosynthesis in cucumber, improve photosynthetic efficiency, and provide more raw materials for sucrose synthesis. At the same time, potassium can also participate in the regulation of sugar metabolism in plants and promote the synthesis of sucrose [32,33]. Cucumber plant growth is inhibited, photosynthesis is weakened, and sucrose synthesis decreases when potassium is deficient. Moreover, potassium deficiency affects nutrient transport and distribution in the plant, resulting in the insufficient accumulation of sucrose in the leaves. Excessive potassium may inhibit the absorption and utilization of other elements (such as nitrogen, calcium, magnesium, etc.) by crops, resulting in element imbalance, affecting physiological metabolism in plants, and, thus, interfering with the synthesis, transportation, and metabolism of sucrose, and its content may also decrease [34–36].

The soluble sugar content in cucumbers usually changes after infection with downy mildew. On the one hand, due to the destruction of the chloroplast structure and function of leaves by bacteria, photosynthesis is affected, resulting in a decrease in the synthesis of photosynthetic products and a corresponding decrease in the synthesis of soluble sugars. On the other hand, in order to resist the infection of bacteria, plants start a series of defense reactions and consume a lot of energy and substances. Soluble sugar is consumed as an important energy source, and its accumulation in the plant decreases [37,38]. In addition, when the disease is severe, the leaves dry up and die, and photosynthesis cannot proceed

normally, which further aggravates the reduction in the soluble sugar content. However, other studies have found that in the early stage of the disease, plants may regulate their metabolism to convert part of the sugars into soluble sugars so as to improve the osmotic pressure in cells and enhance the disease resistance of the plants. At this time, the content of soluble sugars may rise briefly, but it will eventually decline with the development of the disease [39,40]. An appropriate potassium supply can promote the synthesis and transportation of photosynthetic products, enabling the smooth accumulation of soluble sugar from leaves to fruits and other parts, thereby increasing the content of soluble sugar in cucumber fruits. At the same time, potassium can also participate in the regulation of sugar metabolism in plants, promote the synthesis of starch and other polysaccharides, and indirectly affect the content of soluble sugar [41,42]. When potassium is deficient, cucumber plant growth is inhibited, photosynthesis is weakened, sugar synthesis is reduced, and sugar transport and distribution are affected, resulting in an insufficient accumulation of soluble sugar in the leaves [43,44].

4.2. Hydrogen Peroxide (H_2O_2) and Catalase (CAT)

Downy mildew activates cucumber plants' defense response, resulting in the production of reactive oxygen species (ROS) in large quantities, and the content of H_2O_2, as an important ROS, increases significantly [45]. When potassium is deficient, the growth and metabolism of cucumber plants are inhibited, the intracellular reoxidation–reduction balance is unbalanced, reactive oxygen species accumulate, and the content of H_2O_2 increases. Long-term potassium deficiency can lead to inadequate plant nutrition and impaired cell membrane structure and function, and can further aggravate the accumulation of H_2O_2 [46,47].

In the early stages of downy mildew infection, the activity of catalase (CAT) increases rapidly in order to remove excessive H_2O_2 and protect cells from oxidative damage. As the disease progresses, when the bacteria multiply and seriously damage the structure and function of plant cells, the synthesis and activity maintenance of catalase (CAT) may be affected, resulting in a decline in its activity [48]. An appropriate supply of potassium is helpful to maintain the activity of catalase (CAT) in cucumber plants so that the antioxidant system in the cells can effectively remove reactive oxygen species and keep a stable content of H_2O_2. When potassium is deficient, the early plants may increase the activity of catalase (CAT) by inducing the expression of the H_2O_2 gene so as to enhance the ability to remove reactive oxygen species. However, with the aggravation of potassium deficiency and the extension of time, due to poor plant growth, protein synthesis is blocked, and the synthesis and stability of catalase (CAT) are affected, and its activity will eventually decline [49]. When potassium is excessive, due to the imbalance of elements and physiological metabolism disorders in the plant body, the activity of catalase (CAT) may also be inhibited, affecting its ability to remove H_2O_2 and resulting in the accumulation of H_2O_2 [50,51].

4.3. Superoxide Dismutase (SOD), Polyphenol Oxidase (PPO), and Malondialdehyde (MDA)

Downy mildew makes cucumber produce a lot of reactive oxygen species (ROS), which destroy the redox balance in cells. In order to remove excessive reactive oxygen species and protect cells from oxidative damage, cucumber plants activate the antioxidant defense system, in which SOD is one of the key antioxidant enzymes [52]. It is able to convert superoxide anions into hydrogen peroxide, which is then further broken down into water and oxygen by catalase (CAT), thereby reducing the damage by oxidative stress to cells. In the early stage of downy mildew infection, the activity of SOD in cucumber leaves usually increases significantly to enhance the antioxidant capacity of the plant and resist the invasion of pathogens [32]. However, with the development of the disease, SOD

activity may decline when the stress of the plant exceeds its own regulatory ability, which may be due to the proliferation and infection of bacteria that lead to serious damage to the structure and function of plant cells, affecting the synthesis or maintenance of SOD activity [45].

In the case of sufficient potassium, the SOD activity in cucumber roots and leaves can be maintained at a high level because potassium can be used as an activator of SOD to promote its activity [46]. At the same time, potassium can also participate in regulating the osmotic pressure and ion balance in plant cells, stabilize the structure of cell membranes, reduce the production of reactive oxygen species, and indirectly protect the activity of antioxidant enzymes, such as SOD. When potassium stress occurs, whether it is insufficient or excessive potassium, it has an adverse effect on the growth and metabolism of cucumber [48]. When potassium is deficient, cucumber plant growth is inhibited, photosynthesis is weakened, the intracellular redox balance is unbalanced, and reactive oxygen species accumulate, which induce an increase in SOD activity to remove the excessive reactive oxygen species. However, long-term potassium deficiency will lead to plant nutrient deficiency and reduce SOD activity. Excessive potassium may inhibit the absorption and utilization of other elements (such as calcium, magnesium, etc.) by crops, leading to element imbalance, which, in turn, affects the physiological metabolism of plants, and the activity of SOD is also inhibited to some extent [53].

In the early stage of plant disease, the defense mechanism is activated, and PPO activity increases. It can work with peroxidase (POD) to oxidize polyphenols in plants into toxic ketones, thus inhibiting the growth and reproduction of pathogens. At the same time, it also participates in the synthesis of lignin, enhances the mechanical strength of host cells, and limits the uptake of nutrients by pathogens. However, with the development of the disease, when the bacteria proliferate and seriously damage the structure and function of plant cells, the synthesis and activity maintenance of PPO may be affected, resulting in a decline in its activity [54]. An appropriate potassium supply is helpful to maintain the normal physiological function of cucumber plants and keep PPO activity at a relatively stable level. When potassium is deficient, the growth and metabolism of cucumber are affected, the intracellular redox balance is unbalanced, and reactive oxygen species accumulate, which may induce an increase in PPO activity to enhance the plant's defense ability. However, long-term potassium deficiency will lead to plant nutrient deficiency, affect the synthesis and stability of PPO, and, eventually, reduce its activity, which, in turn, will affect the physiological metabolism of the plants, and PPO activity may also be inhibited to a certain extent [50].

Downy mildew destroys the normal physiological function of plant cells and leads to the accumulation of reactive oxygen species (ROS) in cells. These reactive oxygen species can trigger membrane lipid peroxidation and increase the content of malondialdehyde (MDA). Under the condition of sufficient potassium, cucumber plants can maintain a good growth state, the stability of the cell membranes is high, and the antioxidant system in the cells can effectively remove reactive oxygen species, so the content of MDA is at a low level. When potassium is deficient, the growth and metabolism of cucumber plants are inhibited, photosynthesis is weakened, the intracellular redox balance is unbalanced, reactive oxygen species accumulate, membrane lipid peroxidation is enhanced, and the MDA content is increased [55]. Long-term potassium deficiency leads to plant nutrient deficiency, impaired cell membrane structure and function, and the further intensification of MDA accumulation [56].

4.4. Substance Accumulation

As the leaves gradually dry out, the dry matter accumulation is also affected, and the dry weight is reduced [15,57]. When the disease is severe, a large number of leaves wither and die, and the dry and fresh weights of the whole leaves are significantly reduced. Although downy mildew is less harmful to stems than leaves, it can affect the vascular bundle system of stems and hinder the transport of water and nutrients. This results in inhibited stem growth and a slow gain in fresh weight. At the same time, due to the lack of a nutrient supply, the accumulation of dry matter in the stems is also reduced, and the dry weight is relatively low compared with normal plants. Downy mildew mainly affects the above-ground part, but lesions in the above-ground part can affect the root system. On the one hand, the photosynthesis in leaves is weakened, the delivery of photosynthetic products to the roots is reduced, growth is inhibited, and the increase in fresh and dry weights is restricted. On the other hand, overall physiological and metabolic disorders in plants may affect the ability of roots to absorb water and nutrients, further leading to poor root development and a decrease in dry and fresh root weights [58,59].

When potassium is deficient, cucumber leaves grow slowly, the leaf area is small, the color is pale, and the edges are yellow. This is because potassium participates in the processes of photosynthesis and carbohydrate metabolism and transportation, and potassium deficiency leads to poor transport of photosynthetic products, reduced accumulation in leaves, and reduced fresh and dry weights of leaves [16,60]. An appropriate amount of potassium contributes to the robust growth of stems, promotes the synthesis of cellulose and lignin, makes stems tough, enhances lodging resistance, and increases the fresh and dry weights of stems. When potassium is deficient, the stems are thin, growth is slow, the fresh weight increase is not obvious, and the dry weight is lower than the normal level due to the decrease in cellulose and lignin synthesis. Excessive potassium may destroy the ion balance in the plant, affect the normal physiological function of the stems, and negatively affect the dry and fresh weights of the stems [61]. A proper amount of potassium can promote the growth and vitality of roots and develop roots, and the fresh and dry weights of the roots are higher. When potassium deficiency occurs, root growth is inhibited, root elongation and lateral root development are hindered, root vitality is decreased, and the ability to absorb water and nutrients is weakened, resulting in a decrease in the fresh and dry root weights. Excessive potassium may cause ionic toxicity to roots, affect the normal physiological function of root cells, inhibit root growth, and affect their dry and fresh weights [62,63].

5. Conclusions

In order to understand the effects of biotic stress and abiotic stress on hormone metabolism and substance accumulation in cucumber, two different infection levels of downy mildew were set, B0 (diseased) and B1 (disease-free), and T1 (K-50%: 50% of normal potassium application), T2 (K-100%: normal potassium application), and T3 (K-150%: 150% of normal potassium application). The results show that on the 15th day after transplanting, the hormone metabolism in cucumber plants was measured (the incidence of the cucumber plants was grade 3). Downy mildew infection and potassium stress had significant effects on the cane sugar, soluble sugar, hydrogen peroxide (H_2O_2), catalase (CAT), polyphenol oxidase (PPO), malondialdehyde (MDA), and superoxide dismutase (SOD) contents in the cucumber leaves ($p < 0.05$). On the 20th day after transplanting the cucumber plants (the disease degree of the cucumber plants was grade 7), downy mildew infection and potassium stress had significant effects on the dry and fresh weights of the leaves, stems, and roots ($p < 0.05$). This study can provide a theoretical basis for cucumber stress resistance cultivation in greenhouses.

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