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Appropriate Sodium Bicarbonate Concentration Enhances the Intracellular Water Metabolism, Nutrient Transport and Photosynthesis Capacities of *Coix lacryma-jobi* L.

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Abstract: Karst ecological stresses are harmful to plant growth, especially high bicarbonate concentrations, drought, high pH, etc. In this study, the effects of 0, 2.0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate concentrations on the biomass, electrophysiological properties, intracellular water metabolism, nutrient transport, photosynthesis and chlorophyll fluorescence of *Coix lacryma-jobi* L. were investigated. The results show that 2.0 mmol L^{-1} sodium bicarbonate effectively improved the biomass formation of *Coix lacryma-jobi* L., notably increased its intrinsic capacitance (IC) and decreased its intrinsic resistance (IR), intrinsic impedance (IZ), intrinsic capacitive reactance (IXc) and intrinsic inductive reactance (IXL) as well as reliably enhanced its intracellular water metabolism, nutrient transport and photosynthetic capacities. However, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate concentrations exhibited marked inhibitory effects on the plants' photosynthetic rate, stomatal conductance, transpiration rate and dry weight, whereas they did not significantly change the intracellular water metabolism or the nutrient transport capacity of *Coix lacryma-jobi* L. This study highlights that appropriate bicarbonate levels could enhance the intracellular water metabolism, nutrient transport, photosynthesis and growth of *Coix lacryma-jobi* L., which can be rapidly monitored by the plant's electrophysiological properties. Importantly, plant electrophysiological measurement is significantly superior to photosynthesis measurement. In the future, plant electrophysiological measurement can be used as a means to quickly and effectively evaluate the physiological response of plants to the external environment.

Keywords: dissolved inorganic carbon; karst; *Coix* seed rice; electrical signal; substance transport

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1. Introduction

Strong karstification leads to high bicarbonate concentrations, drought, high pH, high calcium and magnesium levels and low nutrition in karst soil environments [1]. In karst ecological systems, stable bicarbonate (HCO_3^-) reservoirs in soil and water can be formed by the dissolution of limestone and dolomite by water, as their HCO_3^- concentrations are notably higher than those of non-karst areas [2]. For instance, in the present literature, it was reported that the HCO_3^- concentration in calcareous soils is usually 1~5 mmol L^{-1} [3,4]; Zhang et al., showed that the HCO_3^- concentration in karst rivers and lakes is usually about 4.5 mmol L^{-1} [5], and Hussner et al., reported that the HCO_3^- concentration was usually several times higher than that of carbon dioxide if the ambient pH value was above 7 [6]. Plants grown in karst areas often suffer from various degrees of karst ecological stresses, such as high bicarbonate levels, drought, high pH, etc. [7]. Consequently, plants' adaptive mechanisms to karst environments is a permanent research hot spot.

Previous studies have reported that karstification has many negative effects on plant growth and metabolism. It affects the growth and photosynthesis of plants by inducing HCO_3^- stress in *Broussonetia papyrifera* L. [8] and tomatoes [9] as well as through decreasing the activity of key enzymes in wheat under drought conditions [10]. Alkali stress affects the growth and physiological characteristics of melon seedlings [11]. High concentrations of HCO_3^- can reduce the uptake of Fe in plants by limiting the expression of Fe acquisition genes, leading to Fe deficiency [12,13]. Fe deficiency strongly limits the biosynthesis of chlorophyll [14], which will result in a significant decrease in photosynthesis. In fact, plants are very tenacious, and they have developed a variety of unique adaptive mechanisms to adversity [15]. Some reports show that HCO_3^- not only provides short-term carbon and water sources for plants under drought stress, but also promotes stomatal opening and restores photosynthesis [16–20]. Meanwhile, HCO_3^- can promote carbon and nitrogen metabolism by regulating the activities of key enzymes involved in carbon and nitrogen metabolism and by participating in the regulation of complex physiological processes, including carbon assimilation and nitrogen reduction in plants [15,21]. Zhou et al., reported that 3~4 mmol L^{-1} sodium bicarbonate concentration added to cultures was conducive to growth and the improvement of carbonic anhydrase activity in macroalgae [22]. Additionally, HCO_3^- can also change the activity of glycolysis and pentose phosphate pathways via the distribution of their substrates to enhance the stress resistance of plants and obtain survival opportunities [8]. Wu et al., systematically summarized the karst-adaptive mechanisms of plants in terms of morphology, ecology, photosynthetic capacity, utilization of inorganic nutrients, carbonic anhydrase activity, biodiversity, calcium regulation root organic acid exudation, etc. [1].

Coix lacryma-jobi L., a typical karst and oldest grass crop, is rich in protein, oil and medicinal components, such as fatty acids, amino acids, triterpenes, vitamins and various minerals [23,24]. Due to its high nutritional and medical value, it is widely used in improving immunity, inhibiting tumor angiogenesis, invigorating stomach and spleen tissue and regulating blood sugar; in addition, it possesses anti-tumor, anti-convulsant and apocenosis effects [25,26]. As a promising economic crop and natural medicine, *Coix lacryma-jobi* L. is widely planted in Southwestern China, especially in Guizhou Province. Currently, the planting area and yield of *Coix lacryma-jobi* L. in China is estimated to be around 73,000 ha and 0.22 million tons, respectively [24,27]. Recently, Guizhou's *Coix lacryma-jobi* L. industry has developed rapidly, becoming the largest producer and distribution center for *Coix lacryma-jobi* L. in Southeast Asia [24]. Moreover, it has made great contributions in alleviating poverty, revitalizing rural areas and controlling rocky desertification, and its planting area reached over 48,600 ha by 2021 [27,28]. In Guizhou Province, however, *Coix lacryma-jobi* L. is mostly planted in karst soil environments, and its growth and development are influenced by many adversities such as high bicarbonate content, drought and high pH levels. Therefore, it is worth exploring whether high levels of bicarbonate can promote the growth of *Coix lacryma-jobi* L. Moreover, to date, there are no data available about the adaptive mechanisms of *Coix lacryma-jobi* L. to high bicarbonate levels.

The electrophysiological activities of plants, including charge separation, electron movement, proton and dielectric transport, etc., control almost all of their biological processes [29–33]. Alterations in plants' electrical parameters are considered to be their fastest response to environmental stresses [34–37]. Numerous findings have shown that the passive electric properties of plants, such as their capacitance (C), impedance (Z), resistance (R), capacitive reactance (Xc) and inductive reactance (XL), can be used to evaluate their physiological status [33–45]. For instance, Zhang et al. found that the theoretical relationships among the clamping force (F) and leaf Z, R, Xc or XL were revealed to be Z, R, Xc or $XL = y + ke^{-bF}$ based on bioenergetics. Then, the intrinsic R (IR), intrinsic Z (IZ), intrinsic Xc (IXc) and intrinsic XL (IXL) of plant leaves were successfully described as IR, IZ, IXc or $IXL = y + k$ when the clamping force is 0 ($F = 0$) [44,45]. Meanwhile, they also developed intracellular water metabolism and nutrient transport parameters based on the IR, IZ, IXc, IXL and intrinsic capacitance (IC) of plants, which accurately revealed the intracellular water metabolism and nutrient transport strategies of plants and allowed them to be evaluated [33,43–45]. Thus, whether plants' electrophysiological properties can be faster and more effective to determine the appropriate bicarbonate level for *Coix lacryma-jobi* L. growth compared to common photosynthesis indicators is worth further attention.

In this study, the effects of sodium bicarbonate on the growth of *Coix lacryma-jobi* L. were evaluated. Moreover, the effects of sodium bicarbonate on the electrophysiological properties, intracellular water metabolism, nutrient transport, photosynthesis and chlorophyll fluorescence of *Coix lacryma-jobi* L. were also investigated. This work provides a scientific basis for rapidly screening the appropriate bicarbonate level for *Coix lacryma-jobi* L. grown in karst environments.

2. Materials and Methods

2.1. Materials

Sodium bicarbonate (AR, ≥99.8%) was provided by Rhawn Reagent Chemical Technology Co., Ltd. (Shanghai, China). All reagents were analytical grade. Three-leaf seedlings of *Coix lacryma-jobi* L. 'Yizhu 1′ with similar growth were used as experimental materials. The seedlings were grown in hydroponic conditions for 14 days. The weights of the aboveground parts were as follows: 0.38 ± 0.01 (fresh); 0.04 ± 0.01 (dry). The weights of the root were as follows: 0.17 ± 0.03 (fresh); 0.02 ± 0.01 (dry). Hoagland nutrient solution contained the following (in mmol L^{-1}): 3.0 mmol KNO_3, 0.125 mmol $NH_4H_2PO_4$, 0.1875 mmol $(NH_4)_2SO_4$, 1.0 mmol $MgSO_4$, 2.0 mmol $Ca(NO_3)_2$, 2.0 µmol KCl, 25 µmol H_3BO_3, 2 µmol $MnSO_4$, 2 µmol $ZnSO_4$, 0.1 µmol $CuSO_4$, 0.1 µmol Na_2MoO_4, 0.043 µmol $CoCl_2$ and 50 µmol Fe-EDTA.

2.2. Sodium Bicarbonate Hydroponic Experiment Using Coix lacryma-jobi L.

The hydroponic method was used for studying the growth effects of sodium bicarbonate on *Coix lacryma-jobi* L. The culture solution was 1/2 Hogland nutrient solution containing different sodium bicarbonate concentrations. Based on the preliminary experimental results and the sodium bicarbonate concentration (1.2~3.3 mmol L^{-1}) in field planting soils of *Coix lacryma-jobi* L., four treatments were designed with 0 (CK), 2.0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate. Each treatment had three replicates, and each replicate contained nine plants as biological replicates. Three plants were randomly selected for each replicate. The original culture solution was replaced with fresh culture solution with a pH of 8.00 ± 0.10 each day, and the whole treatment cycle was 14 days. The culture temperature, illumination time, illumination intensity and relative humidity of *Coix lacryma-jobi* plants were 25.0 ± 2.0/19.0 ± 2.0 °C (light/dark), 12 h/12 h (light/dark), 500.0 ± 25.0 µmol m^{-2} s^{-1} and 55.4~60.6%, respectively.

2.3. Determination of Biomass Parameters, Electrophysiological and Photosynthetic Characteristics and Chlorophyll Fluorescence

The height and weight of *Coix lacryma-jobi* L. plants were measured. The plant height of *Coix lacryma-jobi* L. was measured using a ruler. The fresh weights of the aboveground parts and root were measured by weighing them, and their dry weights were determined after drying them to a constant weight. The fresh weight of a whole *Coix lacryma-jobi* L. plant was the sum of the fresh weights of its aboveground parts and roots, and its whole dry weight was the sum of the dry weights of the aboveground parts and roots.

The intracellular water metabolism and nutrient transport parameters of *Coix lacryma-jobi* L. were determined as described by Zhang et al. [33,44,45]. The fresh second fully expanded leaves of *Coix lacryma-jobi* L. were sampled after measuring their photosynthetic parameters and chlorophyll fluorescence. Leaf samples were immediately soaked in distilled water for 30 min, and then the water on the leaf surface was removed. The electrophysiological parameters of the plant leaves were determined using a LCR-6300 tester (Gwinstek, Taiwan, China) in parallel connection mode with a tested voltage and frequency of 1.5 V and 3 kHz, respectively. The leaf was first put between the two electrodes of a self-made parallel-plate capacitor, and then the leaf's passive electric properties, including C, R and Z under different clamping forces (1.139, 2.149, 3.178, 4.212 and 5.245 N), were continuously recorded, yielding 11~13 data points for each clamping force. Different clamping forces were obtained by adding iron blocks. Subsequently, leaf Xc and XL were calculated based on Equations (1) and (2), respectively.

$$\mathrm{Xc} = \frac{1}{2\pi f C} \tag{1}$$

$$\frac{1}{-\mathrm{XL}} = \frac{1}{\mathrm{Z}} - \frac{1}{\mathrm{R}} - \frac{1}{\mathrm{Xc}} \tag{2}$$

where π is 3.1416 and f is frequency.

The fitting equations for the clamping force and Z, R, Xc, XL and C of the leaves were constructed as Equations (3)–(7):

$$\mathrm{Z} = \mathrm{y_1} + \mathrm{k_1 e^{-b_1 F}} \tag{3}$$

$$\mathrm{R} = \mathrm{y_2} + \mathrm{k_2 e^{-b_2 F}} \tag{4}$$

$$\mathrm{Xc} = \mathrm{y_3} + \mathrm{k_3 e^{-b_3 F}} \tag{5}$$

$$\mathrm{XL} = \mathrm{y_4} + \mathrm{k_4 e^{-b_4 F}} \tag{6}$$

$$\mathrm{C} = \mathrm{y_0} + \mathrm{hF} \tag{7}$$

Furthermore, the real-time intrinsic Z, R, Xc, Xl, C and specific effective thickness (d) of the leaves (F = 0 N) were calculated using the corresponding parameters from Equations (3)–(7):

$$\mathrm{IZ} = \mathrm{y_1} + \mathrm{k_1} \tag{8}$$

$$\mathrm{IR} = \mathrm{y_2} + \mathrm{k_2} \tag{9}$$

$$\mathrm{IX_C} = \mathrm{y_3} + \mathrm{k_3} \tag{10}$$

$$\mathrm{IXL} = \mathrm{y_4} + \mathrm{k_4} \tag{11}$$

$$\mathrm{IC} = \frac{1}{2\pi \mathrm{fIXC}} \tag{12}$$

$$\mathrm{d} = \frac{\mathrm{U^2 h}}{2} \tag{13}$$

where π is 3.1416, f is frequency and U is the tested voltage.

Subsequently, the intracellular water metabolism parameters of *Coix lacryma-jobi* L. including intracellular water-holding capacity (IWHC), intracellular water use efficiency (IWUE), intracellular water-holding time (IWHT) and water transfer rate (WTR) were calculated according to Equations (14)–(17):

$$\mathrm{IWHC} = \sqrt{(\mathrm{IC})^3} \tag{14}$$

$$\mathrm{IWUE} = \frac{\mathrm{d}}{\mathrm{IWHC}} \tag{15}$$

$$\mathrm{IWHT} = \mathrm{IC} \times \mathrm{IZ} \tag{16}$$

$$\mathrm{WTR} = \frac{\mathrm{IWHC}}{\mathrm{IWHT}} \tag{17}$$

Additionally, the intracellular water metabolism parameters of *Coix lacryma-jobi* L., such as nutrient flux per unit area (UNF), active transport flow of nutrient (NAF), nutrient transfer rate (NTR), nutrient transport capacity (NTC) and nutrient active transport capacity (NAC), were calculated according to Equations (18)–(22):

$$\text{UNF} = \frac{\text{IR}}{\text{IXc}} + \frac{\text{IR}}{\text{IXL}} \tag{18}$$

$$\text{NAF} = \frac{\text{IXc}}{\text{IXL}} \tag{19}$$

$$\text{NTR} = \text{WTR} \tag{20}$$

$$\text{NTC} = \text{UNF} \times \text{NTR} \tag{21}$$

$$\text{NAC} = \text{UAF} \times \text{NTR} \tag{22}$$

The chlorophyll content of the second fully expanded leaf of each *Coix lacryma-jobi* L. specimen was measured using a SPAD-502Plus chlorophyll meter (Konica Minolta Inc., Tokyo, Japan). The net photosynthetic rate (Pn), stomatal conductance (Gs) and transpiration rate (Tr) of the second fully expanded leaf of each *Coix lacryma-jobi* L. specimen was determined using a portable Li-6800 photosynthesis measurement system (LI-COR Inc., Lincoln, NE, USA) between 8:00 and 10:00 a.m. The measurement conditions were a flow rate of gas of 500 mmol s^{-1}, photosynthetic active radiation of 500 μmol m^{-2} s^{-1}, leaf temperature of 27 °C and CO_2 concentration of 400 μmol mol^{-1}. The chlorophyll fluorescence parameters of *Coix lacryma-jobi* L. leaves were also measured using a portable Li-6800 photosynthesis measurement system after dark adaptation for 1 h. First, the initial fluorescence (Fo) and maximum fluorescence (Fm) of *Coix lacryma-jobi* L. leaves were determined under dark adaptation conditions, and the maximum photochemical efficiency (Fv/Fm) of PSII was calculated according to Equation (23). Moreover, the maximum fluorescence (Fm′) and stable fluorescence (Fs) of *Coix lacryma-jobi* L. leaves were determined under light adaptation conditions, and the actual photosynthetic efficiency (Φp) of PSII was calculated according to Equation (24).

$$\frac{F_v}{F_m} = \frac{F_m - F_0}{F_m} \tag{23}$$

$$\Phi p = \frac{F_{m'} - F_s}{F_{m'}} \tag{24}$$

2.4. Statistical Analyses

Data are displayed as means ± standard deviation (SD) of three replicates, and all analyses were carried out using SPSS 18.0 (SPSS Inc., Chicago, IL, USA). The data were subjected to analysis of variance (ANOVA) tests. The means of the different groups were compared via Tukey's test ($p < 0.05$). Small letters indicate significant differences between treatments ($n = 3$; $p < 0.05$).

3. Results

3.1. Responses of the Growth in Coix lacryma-jobi L. to Sodium Bicarbonate

The effects of sodium bicarbonate on the growth of *Coix lacryma-jobi* L. are shown in Figure 1. A 2.0 mmol L^{-1} concentration of sodium bicarbonate significantly ($p < 0.05$) promoted plant growth, shoot fresh weight and plant fresh weight compared to CK. A 7.0 mmol L^{-1} concentration of sodium bicarbonate decreased the plant height, aboveground part fresh weight and root fresh weight of *Coix lacryma-jobi* L., whereas the difference between 7.0 mmol L^{-1} sodium bicarbonate and CK did not reach a significant level. A 12.0 mmol L^{-1} concentration of sodium bicarbonate further reduced *Coix lacryma-jobi* L. growth compared with 7.0 mmol L^{-1} sodium bicarbonate.

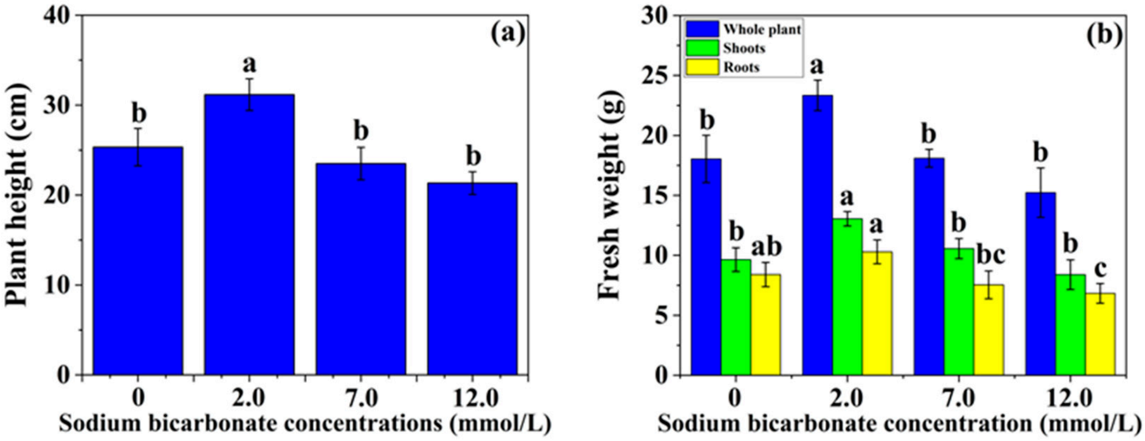

Figure 1. Effects of sodium bicarbonate on the growth of *Coix lacryma-jobi* L. Small letters indicate significant differences between treatments ($n = 3$; $p < 0.05$ according to Tukey's HSD). (**a**) plant height; (**b**) fresh weight.

3.2. Responses of Electrophysiological, Intracellular Water Metabolism and Nutrient Transport Parameters of Coix lacryma-jobi L. to Sodium Bicarbonate

The effects of sodium bicarbonate on the electrophysiological parameters of *Coix lacryma-jobi* L. are shown in Table 1. The plant treated with 2.0 mmol L^{-1} sodium bicarbonate became vigorous, its IC value was higher and its IR, IZ, IXc and IXL values were lower. Sodium bicarbonate effectively increased the IC of *Coix lacryma-jobi* L. and decreased its IR, IZ, IXc and IXL. A 2.0 mmol L^{-1} concentration of sodium bicarbonate significantly ($p < 0.05$) enhanced the IC of *Coix lacryma-jobi* L. and decreased its IR, IZ, IXc and IXL compared to CK. Although 7.0 and 12.0 mmol L^{-1} sodium bicarbonate also decreased the IC of *Coix lacryma-jobi* L. and increased its IR, IZ, IXc and IXL, these electrophysiological parameters were not significantly ($p < 0.05$) different compared to the 0 mmol L^{-1} sodium bicarbonate treatments. These findings emphasize that 2.0 mmol L^{-1} sodium bicarbonate can effectively enhance the IC of *Coix lacryma-jobi* L., decrease its IR, IZ, IXc and IXL and promote its healthy growth.

Table 1. Effects of sodium bicarbonate on the electrophysiological parameters of *Coix lacryma-jobi* L.

$[HCO_3^-]$ (mmol L^{-1})	IC (pF)	IR (MΩ)	IZ (MΩ)	IXc (MΩ)	IXL (MΩ)
0	80.35 ± 22.18^{b}	0.79 ± 0.39^{a}	0.52 ± 0.20^{a}	0.70 ± 0.20^{a}	1.26 ± 0.46^{a}
2.0	359.70 ± 44.70^{a}	0.07 ± 0.02^{b}	0.06 ± 0.01^{b}	0.15 ± 0.02^{b}	0.19 ± 0.03^{b}
7.0	108.20 ± 13.75^{b}	0.41 ± 0.04^{ab}	0.31 ± 0.02^{ab}	0.50 ± 0.06^{ab}	0.77 ± 0.04^{ab}
12.0	97.49 ± 36.47^{b}	0.37 ± 0.22^{ab}	0.32 ± 0.17^{ab}	0.61 ± 0.27^{a}	0.83 ± 0.41^{ab}

$[HCO_3^-]$: $NaHCO_3$ concentration added to the culture medium. The data are shown as the mean ± SD. The data were subjected to analysis of variance (ANOVA) tests. The means of the different groups were compared using Tukey's test. Small letters indicate significant differences between treatments ($n = 3$; $p < 0.05$).

The effects of sodium bicarbonate on the intracellular water metabolism characteristics of *Coix lacryma-jobi* L. are shown in Table 2. A 2.0 mmol L^{-1} concentration of sodium bicarbonate significantly ($p < 0.05$) increased the IWHC and WTR of *Coix lacryma-jobi* L. compared to the 0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate treatments. Moreover, 2.0 mmol L^{-1} sodium bicarbonate significantly ($p < 0.05$) decreased the IWHT of *Coix lacryma-jobi* L. compared to CK. At the same time, the d, IWUE, IWHT and WTR of *Coix lacryma-jobi* L. did not show significant ($p < 0.05$) differences between the 0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate treatments. This indicates that there was little difference in the intracellular water-use efficiency of leaves in the 0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate treatments. The present findings show that 2.0 mmol L^{-1} sodium bicarbonate could effectively improve the IWHC and WTR of *Coix lacryma-jobi* L. and promote its intracellular water metabolism.

Table 2. Effects of sodium bicarbonate on the intracellular water metabolism characteristics of *Coix lacryma-jobi* L.

$[HCO_3^-]$ (mmol L^{-1})	d	IWHC	IWUE	IWHT	WTR
0	153.57 ± 99.08 ^{a}	734.05 ± 298.17 ^{b}	0.27 ± 0.28 ^{a}	38.52 ± 7.86 ^{a}	20.51 ± 12.48 ^{b}
2.0	407.40 ± 63.75 ^{a}	6848.49 ± 1263.66 ^{a}	0.06 ± 0.01 ^{a}	21.87 ± 1.96 ^{b}	316.87 ± 80.77 ^{a}
7.0	238.29 ± 176.15 ^{a}	1130.00 ± 217.07 ^{b}	0.20 ± 0.11 ^{a}	33.86 ± 3.24 ^{ab}	33.22 ± 3.83 ^{b}
12.0	181.56 ± 40.55 ^{a}	997.09 ± 524.67 ^{b}	0.22 ± 0.11 ^{a}	27.80 ± 4.85 ^{ab}	36.93 ± 19.39 ^{b}

$[HCO_3^-]$: $NaHCO_3$ concentration added to the culture medium. The data are shown as the mean ± SD. The data were subjected to analysis of variance (ANOVA) tests. The means of the different groups were compared using Tukey's test. Small letters indicate significant differences between treatments ($n = 3$; $p < 0.05$).

The effects of sodium bicarbonate on the nutrient transport characteristics of *Coix lacryma-jobi* L. are shown in Table 3. Compared to CK, 2.0 mmol L^{-1} sodium bicarbonate significantly ($p < 0.05$) increased the NAC of *Coix lacryma-jobi* L., significantly ($p < 0.05$) enhanced its NAF and NTC and significantly ($p < 0.05$) decreased its UNF. Compared to the 7.0 and 12.0 mmol L^{-1} sodium bicarbonate treatments, 2.0 mmol L^{-1} sodium bicarbonate also significantly ($p < 0.05$) increased the NAC of *Coix lacryma-jobi* L. Moreover, the UNF, NAF, NAC and NTC of *Coix lacryma-jobi* L. did not show significant ($p < 0.05$) differences between the 0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate treatments. These findings here emphasize that 2.0 mmol L^{-1} sodium bicarbonate could effectively improve the NAF, NAC and NTC of *Coix lacryma-jobi* L. and promote its nutrient transport processes.

Table 3. Effects of sodium bicarbonate on the nutrient transport characteristics of *Coix lacryma-jobi* L.

$[HCO_3^-]$ (mmol L^{-1})	UNF	NAF	NAC	NTC
0	1.70 ± 0.55 ^{a}	0.58 ± 0.12 ^{b}	12.67 ± 10.15 ^{b}	36.39 ± 4.65 ^{b}
2.0	0.84 ± 0.08 ^{b}	0.77 ± 0.02 ^{a}	245.58 ± 70.30 ^{a}	43.53 ± 0.73 ^{a}
7.0	1.36 ± 0.20 ^{ab}	0.64 ± 0.06 ^{ab}	21.30 ± 1.70 ^{b}	39.13 ± 2.03 ^{ab}
12.0	1.03 ± 0.19 ^{ab}	0.75 ± 0.05 ^{ab}	28.07 ± 15.51 ^{b}	42.71 ± 1.64 ^{ab}

$[HCO_3^-]$: $NaHCO_3$ concentration added to the culture medium. The data are shown as the mean ± SD. The data were subjected to analysis of variance (ANOVA) tests. The means of the different groups were compared using Tukey's test. Small letters indicate significant differences between treatments ($n = 3$; $p < 0.05$).

3.3. Responses of the Photosynthetic Characteristics of Coix lacryma-jobi L. to Sodium Bicarbonate

The effects of sodium bicarbonate on the photosynthetic characteristics of *Coix lacryma-jobi* L. are shown in Figure 2. A 2.0 mmol L^{-1} concentration of sodium bicarbonate effectively increased the chlorophyll content of *Coix lacryma-jobi* L. compared to CK. Plants treated with 2.0 mmol L^{-1} sodium bicarbonate possessed a superior photosynthetic rate of leaves of 20.86 $\mu mol \cdot CO_2 \cdot m^{-2} \cdot s^{-1}$, which was significantly ($p < 0.05$) higher than that of the plants treated with 0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate (1.15-, 1.19- and 1.8-fold higher, respectively). Compared to CK, 7.0 mmol L^{-1} sodium bicarbonate significantly ($p < 0.05$) increased the chlorophyll content of *Coix lacryma-jobi* L. while significantly ($p < 0.05$) decreasing its stomatal conductance and transpiration rate; 12.0 mmol L^{-1} sodium bicarbonate significantly ($p < 0.05$) decreased its photosynthetic rate, stomatal conductance and transpiration rate. These results indicate that 2.0 mmol L^{-1} sodium bicarbonate can enhance the photosynthesis of *Coix lacryma-jobi* L. plants and promote their growth, and that 7.0~12.0 mmol L^{-1} sodium bicarbonate inhibits the growth of *Coix lacryma-job* L.

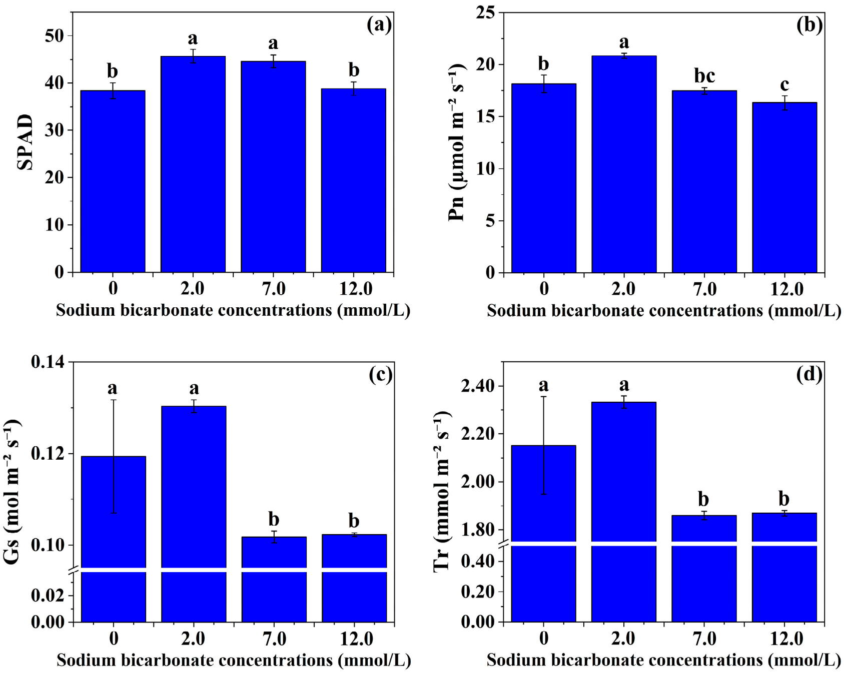

Figure 2. Effects of sodium bicarbonate on the chlorophyll content (SPAD), net photosynthetic rate (Pn), stomatal conductance (Gs) and transpiration rate (Tr) of *Coix lacryma-jobi* L. Small letters indicate significant differences between treatments ($n = 3$; $p < 0.05$ according to Tukey's HSD). (**a**) the chlorophyll content (SPAD); (**b**) net photosynthetic rate (Pn); (**c**) stomatal conductance (Sc); (**d**) transpiration rate (Tr).

3.4. Responses of the Chlorophyll Fluorescence of Coix lacryma-jobi L. to Sodium Bicarbonate

The effects of sodium bicarbonate on the chlorophyll fluorescence characteristics of *Coix lacryma-jobi* L. are shown in Figure 3. There were no significant ($p < 0.05$) differences in the Fv/Fm of *Coix lacryma-jobi* L. between the 0, 2.0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate treatments. A 2.0 mmol L^{-1} concentration of sodium bicarbonate effectively increased the Φp of *Coix lacryma-jobi* L. compared to CK, although the difference was not significant. Concentrations of 7.0 and 12.0 mmol L^{-1} decreased the Φp of *Coix lacryma-jobi* L. compared with 0 mmol L^{-1} sodium bicarbonate, and there was a significant ($p < 0.05$) difference between the 0 and 12.0 mmol L^{-1} sodium bicarbonate treatments. The present findings show that 2.0 mmol L^{-1} sodium bicarbonate can increase the Φp of *Coix lacryma-jobi* L., thereby enhancing its photosynthetic capacity.

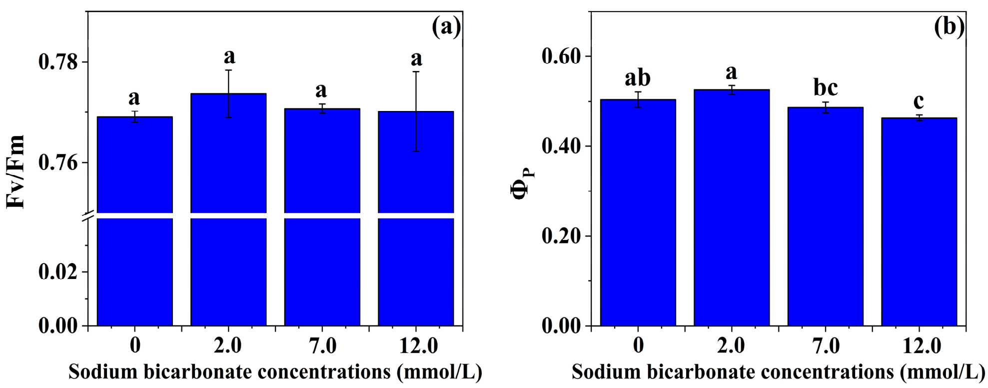

Figure 3. Effects of sodium bicarbonate on the maximum photochemical efficiency (Fv/Fm) and actual photosynthetic efficiency (Φp) of PSII in *Coix lacryma-jobi* L. Small letters indicate significant differences between treatments ($n = 3$; $p < 0.05$ according to Tukey's HSD). (**a**) the maximum photochemical efficiency (Fv/Fm); (**b**) actual photosynthetic efficiency (Φp) of PSII.

4. Discussion

Sodium bicarbonate can not only increase the pH of the environment, but it also affects plants' absorption of water and mineral elements [46]. At the appropriate concentrations of sodium bicarbonate, the positive effect is greater than the negative effect, such as being conducive to carbon assimilation, stimulating stomatal opening and improving drought resistance, etc. In contrast, at excessively high levels of sodium bicarbonate, it can bring anionic toxicity, causing effects such as physiological drought, stomata closure, reducing metabolite synthesis and transport rates, etc. It has been reported that high concentrations of HCO_3^- can reduce the uptake of Fe in plants by limiting the expression of Fe acquisition genes, leading to Fe deficiency [12]. Generally, salt stress occurs when the concentration of sodium is in the range of 25–200 mM [47,48]. Hence, the *Coix lacryma-jobi* L. seedlings did not suffer from salt stress because the concentration of sodium bicarbonate was far below 25 mM in this study. The results here demonstrate that 2.0 mmol L^{-1} sodium bicarbonate can effectively enhance the growth of *Coix lacryma-jobi* L., which is probably derived from the long-term domestication of *Coix lacryma-jobi* L. with the appropriate sodium bicarbonate concentration. With increasing HCO_3^- concentrations, the pH of the culture solution increased gradually, which led to a reduction of the absorption of water and inorganic salts by plant roots, thereby affecting the plants' normal growth and development [12,49]. Rao and Wu found similar results in other plant species (*Camptotheca acuminate* seedlings) [15]. The water potential of plant leaves decreased gradually with the increase in sodium bicarbonate concentration, and the transpiration rate of plants under bicarbonate stress decreased significantly. These effects could explain how the 12.0 mmol L^{-1} sodium bicarbonate treatment on *Coix lacryma-job* L. affected its growth. We also found that the sodium bicarbonate concentration in the soils of Guizhou's *Coix lacryma-jobi* L. planting areas was about 1.2~3.3 mmol L^{-1}.

Plants' physiological activities are vigorous in the healthy state, and its cells store more charge (ions, ion groups and electric dipoles), which can be considered as a generalized charging phenomenon [33]. Thus, the stronger the growth of plants, the higher its charge and C value and the lower its R, Z, Xc and XL values. The findings here emphasize that 2.0 mmol L^{-1} sodium bicarbonate can effectively enhance the IC of *Coix lacryma-jobi* L., decrease its IR, IZ, IXc and IXL and promote its healthy growth, whereas these electrophysiological information parameters were not significantly ($p < 0.05$) different between the 0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate treatments. These results demonstrate that the electrical parameters of *Coix lacryma-jobi* L. rapidly responded to bicarbonate stress, and the appropriate bicarbonate concentration can enhance the growth of *Coix lacryma-jobi* L.

The intracellular water metabolism and nutrient transport statuses of plants strongly reflects their growth and development. Zhang et al. reported that *Broussonetia papyrifera* plants grown in agricultural soils had higher IC, d, IWHC, WTR (or NTR), NTC and water content values and lower IZ and IXc values than those grown in moderately rocky, desertified soils [44,45]. The present findings show that 2.0 mmol L^{-1} sodium bicarbonate can effectively improve the IWHC, WTR (or NTR), NAF, NAC and NTC values of *Coix lacryma-jobi* L. and promote its intracellular water metabolism and nutrient transport. Although the d, IWUE, IWHT, WTR (or NTR), IWUE UNF, NAF, NAC and NTC values of *Coix lacryma-jobi* L. were not significantly ($p < 0.05$) different between the 0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate treatments, the 7.0 and 12.0 mmol L^{-1} sodium bicarbonate treatments can improve the IWHC, WTR (or NTR), NAF, NAC and NTC of *Coix lacryma-jobi* L. Zhang et al. also reported four nutrient transport strategies in the tested plants: (1) low UNF, high NTR and high NTC (e.g., *Broussonetia papyrifera* grown in agricultural soils, *Ipomoea batatas* L., *Solanum tuberosum* L.); (2) high UNF, low NTR and low NTC (e.g., *Broussonetia papyrifera* grown in moderately rocky desertified soils, *Senecio scandens* Buch.-Ham. ex D., *Capsicum annuum* L.); (3) high UNF, low NTR and high NTC (e.g., *Rhus chinensis* Mill.); (4) low UNF, high NTR and low NTC (e.g., *Toona sinensis*) [45]. In this study, three nutrient transport strategies were found: (1) high UNF, low NTR and low NTC (0 mmol L^{-1}); (2) low UNF, high NTR and high NTC (2.0 mmol L^{-1}); (3) high UNF, low NTR and high

NTC (7.0 and 12.0 mmol L^{-1}). From this study, we can conclude that plant leaves with high intracellular water-holding capacity (IWHC) have a faster water transfer rate (WTR). These results also show that the appropriate bicarbonate concentration can improve the intracellular water metabolism and nutrient transport of *Coix lacryma-jobi* L., and that *Coix lacryma-jobi* L. can adapt to bicarbonate environments by improving its intracellular water metabolism and nutrient transport capacities. In addition, the inorganic carbon metabolism of *Coix lacryma-jobi* L., which is dependent on both atmospheric and soil inorganic carbon, can be captured by measuring the plant's electrophysiological parameters.

Shahsavandia et al., found that high HCO_3^- concentrations can reduce the chloroplast content of plants by affecting their reduced iron ion amounts [49]. Li et al., reported that high HCO_3^- concentration is a type of abiotic stress, which could affect the water use of plants and thereby inhibit their photosynthetic capacity [50]. Rao and Wu found that the water potential of plant leaves decreased gradually with the increase in sodium bicarbonate concentration, and the transpiration rate of plants under sodium bicarbonate stress decreased significantly [15]. In this work, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate had inhibitory effects on the chlorophyll content, photosynthetic rate, stomatal conductance and transpiration rate of *Coix lacryma-job* L. The intensification of osmotic stress and the decrease in transpiration rate caused by high HCO_3^- concentrations might be the main reasons for the decrease in photosynthetic capacity of *Coix lacryma-job* L. Nevertheless, plants treated with 2.0 mmol L^{-1} sodium bicarbonate possessed a superior photosynthetic rate of 20.86 $\mu mol \cdot CO_2 \cdot m^{-2} \cdot s^{-1}$, which was significantly ($p < 0.05$) higher than those of plants that received the 0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate treatments. These positive effects were probably related to the utilization of HCO_3^- from the soils by *Coix lacryma-jobi* L.; this HCO_3^- is kept in the reaction center of PSII, and it plays an important role in the transfer of electrons in photosynthesis [1,8,15,51–53]. Our previous work has shown that in karst environments, plants can alternatively use bicarbonate from soil and atmospheric carbon dioxide, and when plants encounter some adversity, their stomatal conductance decreases, carbonic anhydrase activity increases, and their use of bicarbonate also increases, thereby improving their intercellular water status, which in turn increases the use of atmospheric carbon dioxide by these plants [1,15,16,20]. Bicarbonates can stimulate plants to release oxygen, which is called the bicarbonate effect [54]. Recently, Wu proposed that sodium bicarbonate may directly participate in photosynthetic O_2 evolution, resulting in the chemical equilibria, $HCO_3^- + H^+ \rightarrow 1/2O_2 + 2e^- + 2H^+ + CO_2$, which provides electrons and concentrating CO_2 in the Calvin cycle, which is involved in photosynthetic carbon assimilation [51,53].

There are many studies on the impact of plants' photosynthetic characteristics [55–57]. Giovanna et al. reported that added HCO_3^- is beneficial for plant growth and improving photosynthetic efficiency [58]. The present findings show that there was no significant ($p < 0.05$) difference in the Fv/Fm of *Coix lacryma-jobi* L. in the 0, 2.0, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate treatments, which indicates that sodium bicarbonate treatment does not damage the reaction center of PSII. Moreover, 2.0 mmol L^{-1} sodium bicarbonate increased the Φp of PSII in *Coix lacryma-jobi* L. and thereby enhanced photosynthesis, which further demonstrates that the appropriate bicarbonate concentration can enhance the photosynthesis and growth of *Coix lacryma-jobi* L.

Plants grown in karst areas often suffer from various degrees of karst ecological stresses including high bicarbonate concentrations, drought and high pH levels [1,7]. In this work, the results show that 2.0 mmol L^{-1} sodium bicarbonate effectively enhanced the photosynthetic rate and Φp of *Coix lacryma-jobi* L., notably increased its IWHC, WTR (or NTR), NAF, NAC and NTC and improved its intracellular water metabolism and nutrient transport, thereby markedly enhancing its growth and biomass formation. Meanwhile, 12.0 mmol L^{-1} sodium bicarbonate exhibited inhibitory effects on the chlorophyll content, photosynthetic rate, stomatal conductance, transpiration rate and biomass of *Coix lacryma-job* L. Generally, the utilization of bicarbonate from soil by plants is difficult to measure. The results indicate that the inorganic carbon used by *Coix lacryma-jobi* L., which comes from both atmosphere and soil, can be studied using measurements of plants' electrophysiological parameters. This work highlights that the appropriate bicarbonate concentration can improve the intracellular water metabolism, nutrient transport, photosynthetic capacity and growth of *Coix lacryma-jobi* L., and plants' electrophysiological parameters can be used for determining the appropriate bicarbonate level.

5. Conclusions

In conclusion, the present study indicates that 2.0 mmol L^{-1} sodium bicarbonate effectively improves the biomass formation of *Coix lacryma-jobi* L. and notably increases its IC and decrease its IR, IZ, IXc and IXL as well as reliably enhances its intracellular water metabolism, nutrient transport and photosynthesis capacity. Moreover, 7.0 and 12.0 mmol L^{-1} sodium bicarbonate exhibited inhibitory effects on the chlorophyll content, photosynthetic rate, stomatal conductance, transpiration rate and biomass of *Coix lacryma-job* L. This study highlights that the appropriate level of bicarbonate can enhance the intracellular water metabolism, nutrient transport, photosynthetic capacity and growth of *Coix lacryma-jobi* L., and its appropriate bicarbonate level can be rapidly obtained using plants' electrophysiological parameters.

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Abbreviations

HCO_3^-	sodium bicarbonate
C	capacitance
Z	impedance
R	resistance
F	force
d	specific effective thickness
Xc	capacitive reactance
XL	inductive reactance
IC	intrinsic capacitance
IR	intrinsic resistance
IZ	intrinsic impedance
IXc	intrinsic capacitive reactance
IXL	intrinsic inductive reactance
IWHC	intracellular water-holding capacity
IWUE	intracellular water use efficiency
IWHT	intracellular water-holding time
WTR	water transfer rate
UNF	nutrient flux per unit area
NAF	active transport flow of nutrient
NTR	nutrient transfer rate
NTC	nutrient transport capacity
NAC	nutrient active transport capacity

References

1. Wu, Y.; Xing, D.; Hang, H.; Zhao, K. *Principles and Technology of Determination on Plant' Adaptation to Karst Environment*; Science Press: Beijing, China, 2019; pp. 1–88.
2. Stokes, T.R.; Griffiths, P.A. An overview of the Karst Areas in British Columbia, Canada. *Geosci. Can.* **2019**, *46*, 49–66. [CrossRef]
3. Luo, L.; Wu, Y.; Li, H.; Xing, D.; Zhou, Y.; Xia, A. Drought Induced Dynamic Traits of Soil Water and Inorganic Carbon in Different Karst Habitats. *Water* **2022**, *14*, 3837. [CrossRef]
4. McCray, J.M.; Matocha, J.E. Effects of soil water levels on solution bicarbonate, chlorosis and growth of sorghum. *J. Plant Nutr.* **1992**, *15*, 1877–1890. [CrossRef]
5. Zhang, C.; Wang, J.; Pu, J.; Yan, J. Bicarbonate daily variations in a karst river: The carbon sink effect of subaquatic vegetation photosynthesis. *Acta Geol. Sin.-Engl.* **2012**, *86*, 973–979. [CrossRef]
6. Hussner, A.; Mettler-Altmann, T.; Weber, A.; Sand-Jense, K. Acclimation of photosynthesis to supersaturated CO_2 in aquatic plant bicarbonate users. *Freshw. Biol.* **2016**, *61*, 1720–1732. [CrossRef]
7. Xing, D.; Chen, X.; Wu, Y.; Xu, X.; Chen, Q.; Li, L.; Zhang, C. Rapid prediction of the re-watering time point of *Orychophragmus violaceus* L. based on the online monitoring of electrophysiological indexes. *Sci. Hortic.* **2019**, *256*, 108642. [CrossRef]
8. Yao, K.; Wu, Y. Rhizospheric bicarbonate improves glucose metabolism and stress tolerance of *Broussonetia papyrifera* L. seedlings under simulated drought stress. *Russ. J. Plant Physl.* **2021**, *68*, 126–135. [CrossRef]
9. Gong, B.; Wen, D.; Vandenlangenberg, K.; Wei, M.; Yang, F.; Shi, Q.; Wang, X. Comparative effects of NaCl and $NaHCO_3$ stress on photosynthetic parameters, nutrient metabolism, and the antioxidant system in tomato leaves. *Sci. Hortic.* **2013**, *157*, 1–12. [CrossRef]
10. Zhang, X.; Pu, P.; Tang, Y.; Zhang, L.; Lv, J. C_4 photosynthetic enzymes play a key role in wheat spike bracts primary carbon metabolism response under water deficit. *Plant Physiol. Biochem.* **2019**, *142*, 163–172. [CrossRef]
11. Sun, X.; Dong, X.; Li, X.; Chen, L.; Liu, J. Response of growth and physiological characteristics of melon seedlings under alkali stress. *North Hortic.* **2020**, *9*, 51–59. [CrossRef]
12. García, M.J.; García-Mateo, M.J.; Lucena, C.; Romera, F.J.; Rojas, C.L.; Alcántara, E.; Pérez-Vicente, R. Hypoxia and bicarbonate could limit the expression of iron acquisition genes in Strategy I plants by affecting ethylene synthesis and signaling in different ways. *Physiol. Plant.* **2014**, *150*, 95–106. [CrossRef]
13. Ding, W.; Clode, P.L.; Lambers, H. Effects of pH and bicarbonate on the nutrient status and growth of three Lupinus species. *Plant Soil.* **2020**, *447*, 9–28. [CrossRef]
14. Kallala, N.; M'sehli, W.; Jelali, K.; Kais, Z.; Mhadhbi, H. Inoculation with efficient nitrogen fixing and indoleacetic acid producing bacterial microsymbiont enhance tolerance of the model legume *Medicago truncatula* to iron deficiency. *Biomed Res. Int.* **2018**, *2018*, 9134716. [CrossRef] [PubMed]
15. Rao, S.; Wu, Y. Root derived bicarbonate assimilation in response to variable water deficit in *Camptotheca acuminata* seedlings. *Photosynth. Res.* **2017**, *134*, 59–70. [CrossRef] [PubMed]
16. Wu, Y. Strategies to increase carbon fixation and sequestration by karst-adaptable plants. *Carsol. Sin.* **2011**, *30*, 461–465. [CrossRef]
17. Tang, Y.; Lian, B. Diversity of endolithic fungal communities in dolomite and limestone rocks from Nanjiang canyon in Guizhou karst area, China. *Can. J. Microbiol.* **2012**, *58*, 685–693. [CrossRef] [PubMed]
18. Wang, R.; Wu, Y.; Xing, D.; Hang, H.; Liu, Y.; Zhang, K.; Yan, K. Physiological characteristics and inorganic carbon usage capacity of three biomass plants under simulative karst adversity (bicarbonate stress). *Earth Environ.* **2015**, *43*, 21–30. [CrossRef]
19. Hang, H.; Wu, Y. Quantification of photosynthetic inorganic carbon utilisation via a bidirectional stable carbon isotope tracer. *Acta Geochim.* **2016**, *35*, 130–137. [CrossRef]
20. Wang, R.; Wu, Y.; Xing, D. Biomass production of three biofuel energy plants'use of a new carbon resource by carbonic anhydrase in simulated karst soils: Mechanism and capacity. *Energies* **2017**, *10*, 1370. [CrossRef]
21. Banerjee, G.; Ghosh, I.; Kim, C.J.; Debus, R.J.; Brudvig, G.W. Bicarbonate rescues damaged proton-transfer pathway in photosystem II. *BBA-Bioenerg.* **2019**, *1860*, 611–617. [CrossRef]
22. Zhou, W.; Sui, Z.; Wang, J.; Hu, Y.; Kang, K.H.; Hong, H.R.; Niaz, Z.; Wei, H.; Du, Q.; Peng, C.; et al. Effects of sodium bicarbonate concentration on growth, photosynthesis, and carbonic anhydrase activity of macroalgae *Gracilariopsis lemaneiformis, Gracilaria vermiculophylla*, and *Gracilaria chouae* (Gracilariales, Rhodophyta). *Photosynth. Res.* **2016**, *128*, 259–270. [CrossRef]
23. Fu, Y.; Yang, C.; Meng, Q.; Liu, F.; Shen, G.; Zhou, M.; Ao, M. Genetic diversity and structure of *Coix lacryma-jobi* L. from its world secondary diversity center, southwest China. *Int. J. Genom.* **2019**, *2019*, 9815697. [CrossRef]
24. Miao, G.; Qin, Y.; Guo, J.; Zhang, Q.; Bao, Y. Transcriptome characterization and expression profile of *Coix lacryma-jobi* L. in response to drought. *PLoS ONE* **2021**, *16*, e0256875. [CrossRef] [PubMed]
25. Lee, Y.J.; Park, H.J.; Cho, S.J.; Park, S.A.; Kim, M.L. The effect of yulmu (*Coix lacryma-jobi* L.)-sunsik on obesity and hyperlipidemia in mice fed high-fat diet. *J. Korean Soc. Food Sci. Nutr.* **2021**, *50*, 664–671. [CrossRef]
26. Yu, Q.; Ye, G.; Lei, Z.; Yang, R.; Chen, R.; He, T.; Huang, S. An isolated compound from stems and leaves of *Coix lacryma-jobi* L. and its anticancer effect. *Food Biosci.* **2021**, *42*, 101047. [CrossRef]
27. Diao, X. Production and genetic improvement of minor cereals in China. *Crop. J.* **2017**, *5*, 103–114. [CrossRef]

28. Li, X.; Lu, X.; Pan, H.; Wei, X.; Shi, M.; Su, Y. Research status of germplasm resource and genetic breeding in *Coix lacryma-jobi* L. *Guizhou Agri. Sci.* **2022**, *50*, 8–15. [CrossRef]
29. Fromm, J.; Lautner, S. Electrical signals and their physiological significance in plants. *Plant Cell Environ.* **2007**, *30*, 249–257. [CrossRef]
30. Volkov, A.G. *Plant Electrophysiology*; Theory and Methods; Springer: Berlin/Heidelberg, Germany, 2006.
31. Szechyńska-Hebda, M.; Lewandowska, M.; Karpiński, S. Electrical signaling, photosynthesis and systemic acquired acclimation. *Front. Physiol.* **2017**, *8*, 684. [CrossRef] [PubMed]
32. Sukhov, V. Electrical signals as mechanism of photosynthesis regulation in plants. *Photosynth. Res.* **2016**, *130*, 373–387. [CrossRef]
33. Zhang, C.; Su, Y.; Wu, Y.; Li, H.; Zhou, Y.; Xing, D. Comparison on the nutrient plunder capacity of *Orychophragmus violaceus* and *Brassica napus* L. Based on electrophysiological properties. *Horticulturae* **2021**, *7*, 206. [CrossRef]
34. Sukhov, V.; Gaspirovich, V.; Mysyagin, S.; Vodeneev, V. High-temperature tolerance of photosynthesis can be linked to local electrical responses in leaves of Pea. *Front. Physiol.* **2017**, *8*, 763. [CrossRef] [PubMed]
35. Sukhov, V.; Surova, L.; Sherstneva, O.; Bushueva, A.; Vodeneev, V. Variation potential induces decreased PSI damage and increased PSII damage under high external temperatures in pea. *Funct. Plant Biol.* **2015**, *42*, 727–736. [CrossRef] [PubMed]
36. Gil, P.M.; Gurovich, L.; Schaffer, B.; Alcayaga, J.; Rey, S.; Iturriaga, R. Root to leaf electrical signaling in avocado in response to light and soil water content. *J. Plant Physiol.* **2008**, *165*, 1070–1078. [CrossRef]
37. Zhang, M.; Wu, Y.; Xing, D.; Zhao, K.; Yu, R. Rapid measurement of drought resistance in plants based on electrophysiological properties. *Trans. ASABE* **2015**, *58*, 1441–1446. [CrossRef]
38. Harker, F.R.; Dunlop, J. Electrical impedance studies of nectarines during coolstorage and fruit ripening. *Postharvest Biol. Technol.* **1994**, *4*, 125–134. [CrossRef]
39. Ibba, P.; Falco, A.; Abera, B.D.; Cantarella, G.; Petti, L.; Lugli, P. Bio-impedance and circuit parameters: An analysis for tracking fruit ripening. *Postharvest Biol. Technol.* **2020**, *159*, 110978. [CrossRef]
40. Javed, Q.; Wu, Y.; Xing, D.; Azeem, A.; Ullah, I.; Zaman, M. Re-watering: An effective measure to recover growth and photosynthetic characteristics in salt-stressed *Brassica napus* L. *Chil. J. Agric. Res.* **2017**, *77*, 78–86. [CrossRef]
41. Kertész, Á.; Hlaváčová, Z.; Vozáry, E.; Staroňová, L. Relationship between moisture content and electrical impedance of carrot slices during drying. *Int. Agrophys.* **2015**, *29*, 61–66. [CrossRef]
42. Xing, D.; Chen, X.; Wu, Y.; Zwiazek, J.J. Leaf physiological impedance and elasticity modulus in *Orychophragmus violaceus* seedlings subjected to repeated osmotic stress. *Sci. Hortic.* **2021**, *276*, 109763. [CrossRef]
43. Xing, D.; Mao, R.; Li, Z.; Wu, Y.; Qin, X.; Fu, W. Leaf intracellular water transport rate based on physiological impedance: A possible role of leaf internal retained water in photosynthesis and growth of tomatoes. *Front. Plant Sci.* **2022**, *13*, 845628. [CrossRef]
44. Zhang, C.; Wu, Y.; Su, Y.; Xing, D.; Dai, Y.; Wu, Y.; Fang, L. A plant's electrical parameters indicate its physiological state: A study of intracellular water metabolism. *Plants* **2020**, *9*, 1256. [CrossRef] [PubMed]
45. Zhang, C.; Wu, Y.; Su, Y.; Li, H.; Fang, L.; Xing, D. Plant's electrophysiological properties manifests the composition and nutrient transport characteristics of membrane proteins. *Plant Signal. Behav.* **2021**, *16*, e1918867. [CrossRef]
46. Hajiboland, R.; Yang, X.; Romeld, V. Effects of bicarbonate and high pH on growth of Zn-efficient and Zn-inefficient genotypes of rice, wheat and rye. *Plant Soil.* **2003**, *250*, 349–357. [CrossRef]
47. Haro, R.; Banuelos, M.A.; Quintero, F.J.; Rubio, F.; Rodriguez-Navarro, A. Genetic basis of sodium exclusion and sodium tolerance in yeast, A model for plants. *Physiol. Plant.* **1993**, *89*, 868–874. [CrossRef]
48. Gupta, P.; Seth, C.S. 24-Epibrassinolide Regulates Functional Components of Nitric Oxide Signalling and Antioxidant Defense Pathways to Alleviate Salinity Stress in *Brassica juncea* L. cv. Varuna. *J. Plant Growth Regul.* **2023**, *42*, 183–198. [CrossRef]
49. Shahsavandi, F.; Eshghi, S.; Gharaghani, A.; Ghasemi-Fasaei, R.; Jafarinia, M. Effects of bicarbonate induced iron chlorosis on photosynthesis apparatus in grapevine. *Sci. Hortic.* **2020**, *270*, 109427. [CrossRef]
50. Li, R.; Shi, F.; Fukuda, K.; Yang, Y. Effects of salt and alkali stresses on germination, growth, photosynthesis and ion accumulation in alfalfa (*Medicago sativa* L.). *Soil Sci. Plant Nutr.* **2010**, *56*, 725–733. [CrossRef]
51. Wu, Y. Combined effect of bicarbonate and water in photosynthetic oxygen evolution and carbon neutrality. *Acta Geochim.* **2023**, *42*, 77–88. [CrossRef]
52. Tikhonov, K.; Shevela, D.; Klimov, V.V.; Messinger, J. Quantification of bound bicarbonate in photosystem II. *Photosynthetica* **2017**, *56*, 210–216. [CrossRef]
53. Wu, Y. Is bicarbonate directly used as substrate to participate in photosynthetic oxygen evolution. *Acta Geochim.* **2021**, *40*, 650–658. [CrossRef]
54. Warburg, O.; Krippahl, G. Hill-Reaktionen. *Z. Naturforsch.* **1958**, *13*, 509–514. [CrossRef]
55. Agnihotri, A.; Gupta, P.; Dwivedi, A.; Seth, C.S. Counteractive mechanism (s) of salicylic acid in response to lead toxicity in *Brassica juncea* (L.) Czern. cv. Varuna. *Planta* **2018**, *248*, 49–68. [CrossRef]
56. Singh, D.; Agnihotri, A.; Seth, C.S. Interactive effects of EDTA and oxalic acid on chromium uptake, translocation and photosynthetic attributes in Indian mustard (*Brassica juncea* L. var. Varuna). *Curr. Sci.* **2017**, *112*, 2034–2042. [CrossRef]

57. Kumar, D.; Dhankher, O.P.; Tripathi, R.D.; Seth, C.S. Titanium dioxide nanoparticles potentially regulate the mechanism (s) for photosynthetic attributes, genotoxicity, antioxidants defense machinery, and phytochelatins synthesis in relation to hexavalent chromium toxicity in *Helianthus annuus* L. *J. Hazard. Mater.* **2023**, *454*, 131418. [CrossRef] [PubMed]
58. Giovanna, S.; Francesco, B.; Mario, A.; Federica, C.; Olga, M.; Simona, C. Rapid and positive effect of bicarbonate addition on growth and photosynthetic efficiency of the green microalgae *Chlorella Sorokiniana* (Chlorophyta, Trebouxiophyceae). *Appl. Sci.* **2020**, *10*, 4515. [CrossRef]