

Effects of Atmospheric Cold Plasma Treatment on Growth and nutrients of Rice

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Abstract. Plasma treatment of crop seeds is a new agricultural technology developed in recent years, which improves the growth vigor of seeds and promotes plant growth. Rice is one of the most important crops in the world. Its yield increase and quality improvement have been the focus of international research. This article study the effect of arc plasma on the germination and growth of rice seeds, showing the faster germination and more vigorous growth of plasma treated seeds. At tillering stage, the highest plant height, the maximum number of tillers and maximum leaf area of the plasma treated groups increased by 30.7%, 93.75% and 47.28%, respectively. At harvest, the highest yield of plasma treated groups is increased by 28.4%. The correlation between plasma treatment power and the growth parameters including the seedling height, tillering number and plant height at tillering stage was also analyzed, which shows the strong dependence of tillering number on seedling height and plant height. In addition, plant height has strong correlation to seedling height. The comparison of the trace elements and nutrients (niacin, zinc, sodium) shows plasma treatment not only can improve rice growth, but also can adjust nutrients.

Keywords: Cold Plasma; Rice; Growth.

1. Introduction

Rice is a plant of the Gramineae family, and rice is one of the important grains in many countries [1,2]. At present, rice production is mainly increased through fertilizers, pesticides, auxin, and other methods, which promote food production at the cost of huge environmental costs, such as pesticides, fertilizers, pesticides, and other negative effects caused by water quality deterioration, soil acidification, crop quality decline, and food security problems [3]. In recent years, food security caused by environmental degradation and water pollution has become a huge challenge for many countries and regions [4]. In order to solve the above problems, scientists have been exploring green technology to increase production and improve quality.

Plasma is the fourth state of matter consists of ions, electrons, free radicals, ground and excited state molecules, and so on [5,6], and easily reacts with the surface of the substance it contacts. Since the overall gas temperature of low temperature plasma (LTP) can be as low as room temperature, great progresses have been made in the research on the wide application in many fields, such as industry, aerospace, agriculture, and so on [7]. A large number of studies have shown that plasma technology can improve crop yield [8], inhibit diseases and insects [9], and protect the environment [10]. Plasma treatment providing a new way for the future development of agriculture. In 2000, John C. Volin et al. [12] treated seeds of five plants (radish, two kinds of pea, soybean, and kidney bean)

with plasma, and found that the germination rate and water absorption of the treated seeds were improved. With the deepening research on the application of low-temperature plasma in agriculture, the research on the treatment of crop seeds by plasma has been gradually strengthened. In 2005, Yin Meiqiang et al. [13] treated tomato seeds with magnetizing plasma before sowing, and the results showed that plasma treatment could promote the germination rate and emergence rate of soybean and wheat in a certain range. In 2014, the Nanjing Institute of Soil Science, Chinese Academy of Sciences [14] used plasma treatment before soybean planting, and the results showed that appropriate plasma treatment could improve soybean vigor index, seed water absorption rate and dry weight.

In this paper, an arc plasma device was used to treat rice seeds with different treatment time of cold plasma to study the correlation between growth parameters and plasma treatment time and so as to find suitable treatment time for rice seed germination and growth.

2. Materials and Method

As the main rice variety in Jiangsu, China, Nanjing 9108 rice was selected as the object to be treated by and planted in the field. In this article, *arc discharge* was used to treat rice seeds, shown in Fig.1 with the treatment parameters are as follows. The processing power is 455W, the reaction gas is air with the gas flow rate of 1.5 L/min, and the discharge gap is 30 mm. The processing time is 0.6, 1.2, 1.8 and 2.4s, with the group numbers from 1 to 4. The rice planting was performed in Taizhou, a city of Jiangsu Province, China. The rice planting period is from May till November.

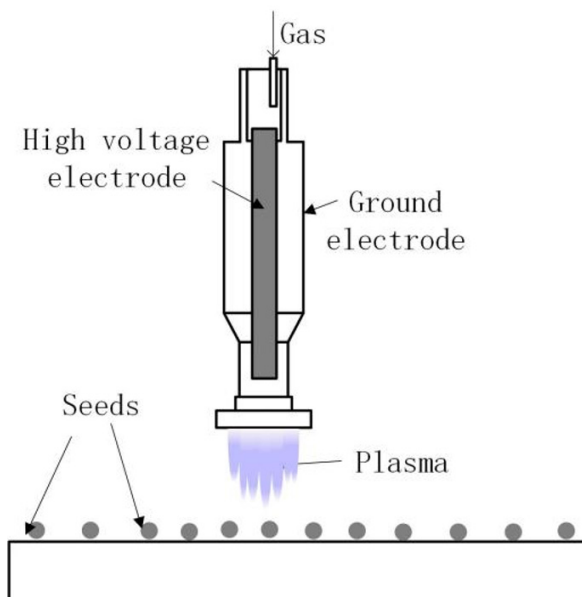


Fig 1. Plasma experimental device

This paper collected the rice height at the seedling and tillering stage, the tillering number and the yield at maturity stage. Then, the rice yield is calculated in the unit of mu ($1 \text{ mu} = 667 \text{ m}^2$) through measuring the weight of the harvested rice of each group with the specific area.

3. Results and Analysis

3.1 The Effect of Plasma Treatment on Rice Growth

Seedling height is one of the important indicators reflecting the biological vitality of rice. Fig 2(a) is the comparison of the seedling height of different groups after 16 days of seedling cultivation. The results show that plasma treatment accelerates seedling height with the maximum increasement of up to 39.38%.

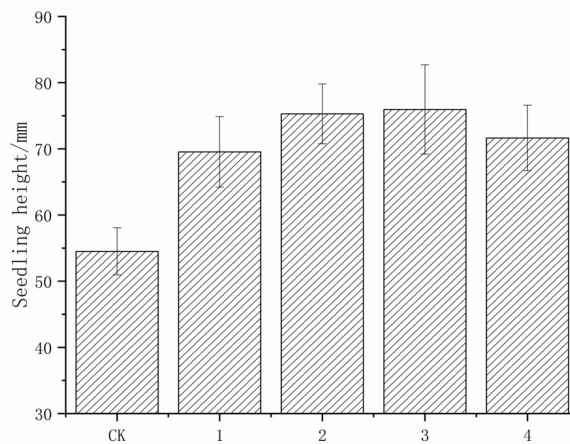
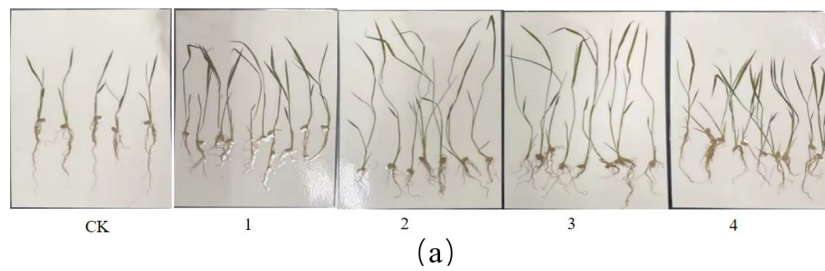


Fig 2. Average rice seedling height contrast

It can be seen from Fig 2(b) that the seedling height of the four groups was higher than that of group CK, among which the seedling height of No.3 group is the highest with the average height of 75.96 mm, which was 21.46 mm higher than group CK (54.5mm). When the treatment time was increased from 0.6 to 1.8 s, the promotion effect became more and more obvious. When the treatment time was continuously increased to 2.4 s, the promotion effect was decreased compared with 1.2 s and 1.8 s. It shows that there is the appropriate treatment dose for plasma promotion on rice. With the overdose, the promoting effect becomes weak, or even suppressed. The seed germination and seedling growth are closely related to the activity of enzyme, which is the physiological and biochemical basis for promoting the growth of seedlings. Peroxidase can catalyze the decomposition of intracellular lipid peroxidation products and reduce the accumulation of intracellular peroxide [15]. Plasma treatment can improve the activity of peroxidase, strengthen the metabolic level of rice seeds, and promote the growth of rice seedlings.

Plant height is not only one of the important indicators reflecting plant vigor, and also one of the most important characteristics related to plant state and potential yield [16]. Fig 3(a) is the individual rice plant of the four groups at the tillering stage and Fig 3(b) is the corresponding plant height at the tillering stage. It shows that the highest plant is 45.67 cm, 28.65% higher than group CK. The results show that cold plasma treatment of seeds has a great effect on the height of rice. The height change trend is similar to that of seedlings.

Rice tillers refer to the branches of rice stalks. The number of tillers per plant plays an important role in rice yield. An appropriate number of tillers is the prerequisite for maintaining the ideal yield of rice. Fig. 4(a) shows the top view of rice in 265 cm × 355 cm at tillering stage. It can be seen from Fig 4(b) that compared with the CK group, the number of rice tillers after plasma treatment increased, and the maximum number of tillers increased by 93.75%. Within the treatment time in 0.6–1.8 s, the tillering number gradually increases. However, when the treatment time continuously increases to 2.4 s, the tiller promotion effect becomes weakened compared with that of 0.6–1.8 s. It shows that there is an optimal treatment time, which can best promote the tillering effect of rice. The improvement of rice tillering may be due to that plasma accelerates the decomposition of stored nutrients in seeds, reduce the relative permeability of rice cell membranes, and increase the root activity and protective enzyme activity of seedlings.

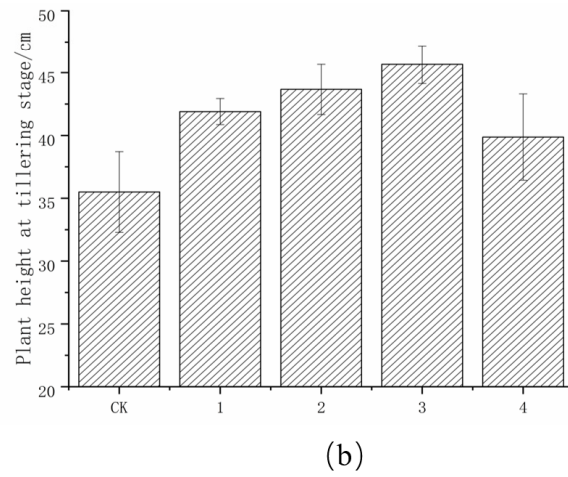
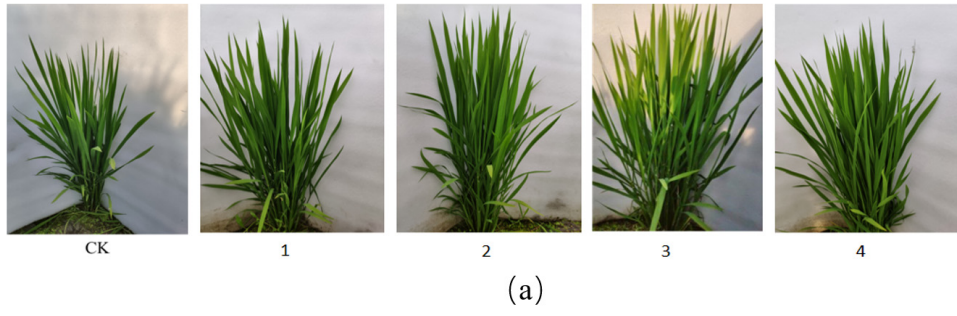


Fig 3. Rice plant height at tillering stage

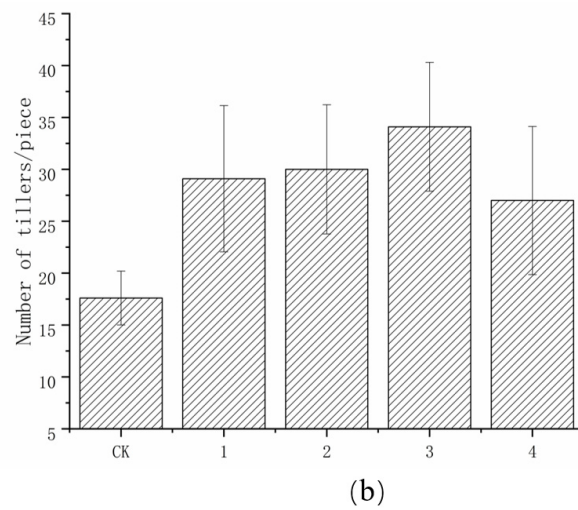
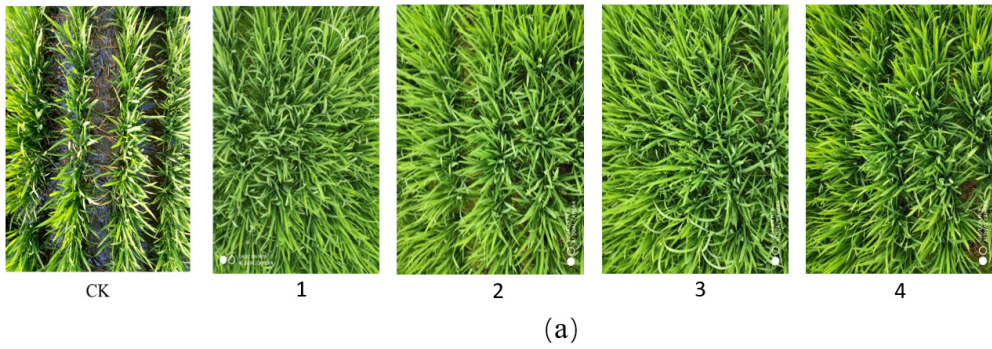


Fig 4. Rice tiller number

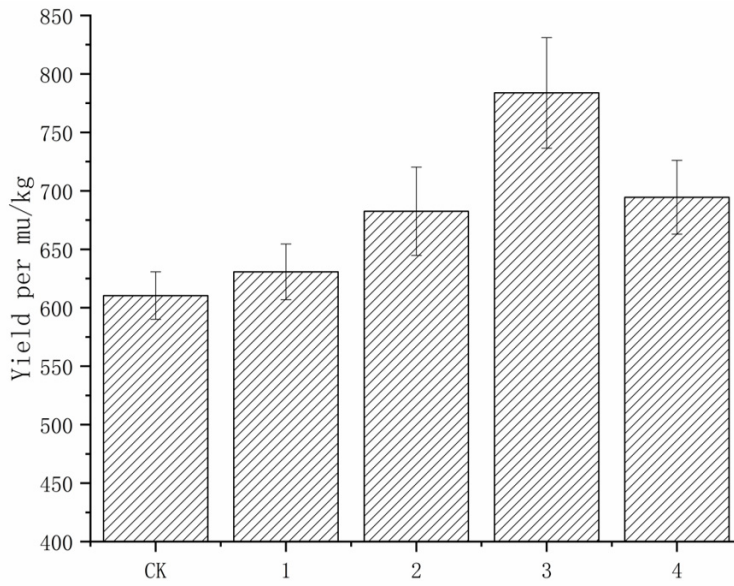


Fig 5. The calculated rice yield per mu

Fig.5 shows the comparison of the calculated rice yield. It shows that the yield of the plasma groups increased by 20.27-173.37 kg/mu, and the highest yield was 783.79 kg, which is 28.4% higher than that of group CK. It indicates that plasma treatment could effectively increase rice yield. Liang Jiuli [17], Shen Youbai [18] researched that the seeds will receive light radiation, electromagnetic radiation, electromagnetic field stimulation and bombardment of charged particles when the rice seeds are treated by plasma, so as to stimulate the activity of various substances inside the seeds and the energy generated, too. Also, during treatment by atmospheric plasma discharge, the produced ozone, which kills bacteria on the surface of the seeds to protect them away from pests and diseases. Furthermore, with the low energy emission of plasma and the short processing time, the seeds will be with the improved vitality so that the internal ion exchange capacity of rice seeds is enhanced, the conversion of enzymes is accelerated, and the content of soluble sugar and soluble protein are increased. According to the above analyses during the entire life cycle of seeds, from germination to maturity, the comprehensive advantages of plasma increases the yield of rice and improves rice quality. In addition, from Fig.5, it also can be seen that when the treatment time continuously increases to 2.4 s, the rice yield promotion effect (only 10.16%) fell down compared with that of 1.8 s, similar to the result of Fig.4. It shows that there is an optimal plasma treatment time for the maximum production. The optimization parameters of plasma treatment include treatment time, discharge voltage, and so on. The study [19] showed that the suitable voltage of plasma treatment, can promote the germination of seeds, and higher voltage will inhibit the germination.

3.2 Significance and Correlation Analysis

One-way ANOVA was conducted for the above indicators. The prerequisite of one-way ANOVA requires the data conform to normal distribution and homogeneity of variance. So, first, the sample data should be tested for normality. Due to the small sample size (<50), we adopted *Shapiro-Wilk* test. Each group of independent variables will have one *Shapiro-Wilk* normality test result. If the data fit the normal distribution, the significance level should be greater than 0.05. The invalid hypothesis of the *Shapiro-Wilk* test is that the data follows normal distribution, and the alternative hypothesis is that the data does not follow normal distribution. Therefore, if the invalid hypothesis is rejected ($P < 0.05$), it means that the data does not obey the normal distribution [20]. In our experiment, the P value of normality test for each group is greater than 0.05, so all indicators of sample data follow normal distribution. At the same time, the homogeneity test of variance was also performed and verified. From Table 1, the *P-value* comparison of different groups shows that there are significant differences

between the control group and the plasma groups. The significance results of each indicator are shown in.

Table 1. The P- value comparison of seedling heights among rice groups

Comparison between groups	seedling height	tiller number	plant height at tillering stage	Yield
CK~Group1	9.87E-10	0.001	9.84E-10	3.10E-5
CK~Group2	8.23E-12	2E-6	8.23E-12	4.51E-14
CK~Group3	4.86E-12	0.001	4.86E-12	1.98E-21
CK~Group4	1.63E-10	0.008	1.63E-10	2.41E-15

In order to study the linear correlation between plasma treatment time and rice growth parameters, Pearson linear correlation coefficient was used. Since normal distribution test was conducted on the above sample data, and all the variables were verified obey to the normal distribution and meet the conditions of Pearson correlation analysis. According to Pearson correlation coefficient range, the coefficient of 0.8-1 means the extremely strong correlation and the coefficient of 0.6-0.8 means the strong correlation between the two variables. It can be seen from Fig. 6 that the correlation between *seedling height*, *plant height* and *tillering number* is extremely strong. In addition, there is a strong correlation between yield and *seedling height*, *plant height*, *tillering number* and *plasma treatment time*, among which the correlation with *tillering number* was the strongest. Thus, the rice yield can be increased by improving *tillering number* with adjusting plasma treatment time.

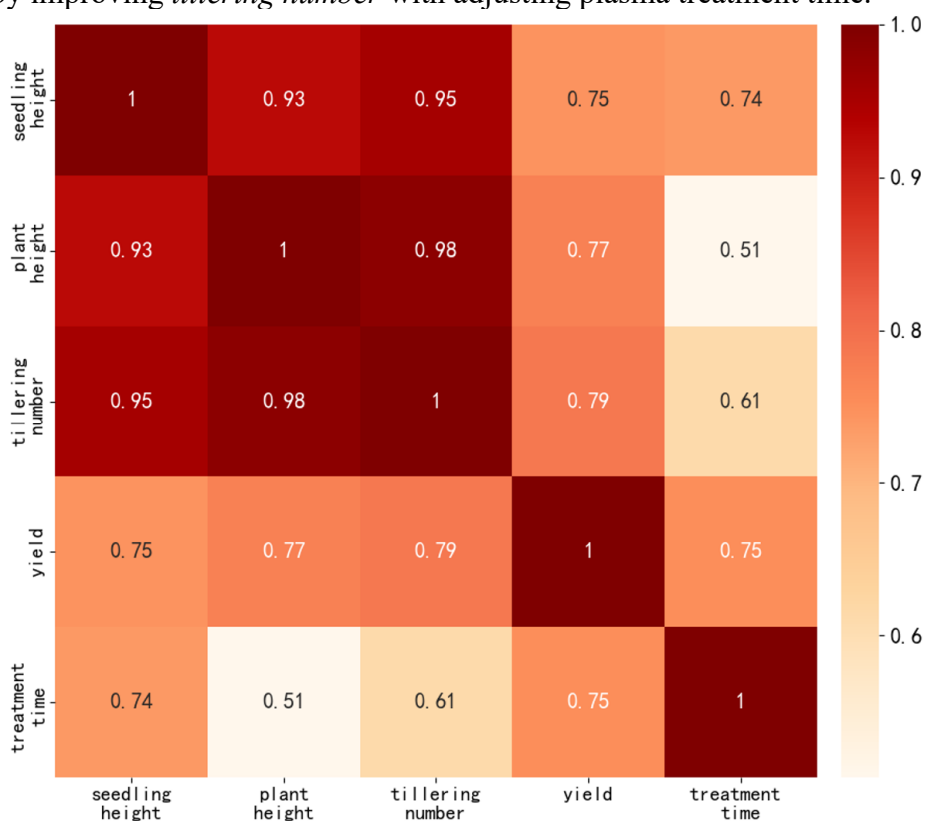


Fig 6. Variable correlation heatmap

3.3 Effects of Plasma Treatment on Trace Elements and Nutrients

Trace elements and nutrient composition of crops are important to measure rice quality to find out how the plasma affect them. The average of nutrient composition of plasma treated groups was shown in Fig.7. Niacin belongs to the B vitamin group and is one of the most stable B vitamins, also known as vitamin B3. It is one of the 13 essential vitamins for the human body. It is widely found in animals and plants, especially used for the prevention and treatment of pellagra [21], and plays a great role in

healing wounds, repairing sunburn and wrinkles [22]. The lack of niacin in animals will affect the synthesis of glycerol and fatty acids, thus affecting the synthesis of fat [23]. Dietary nicotinic acid can significantly reduce serum cholesterol and triglyceride (TG) levels, improve high-density lipoprotein level, and affect fat metabolism [24,25]. Niacin can also effectively reduce cardiovascular risk by lowering serum LDL and triglycerides [26]. As shown in Fig 7, the content of nicotinic acid in the plasma treatment group (AD) was 1.6 times higher than that in the control group.

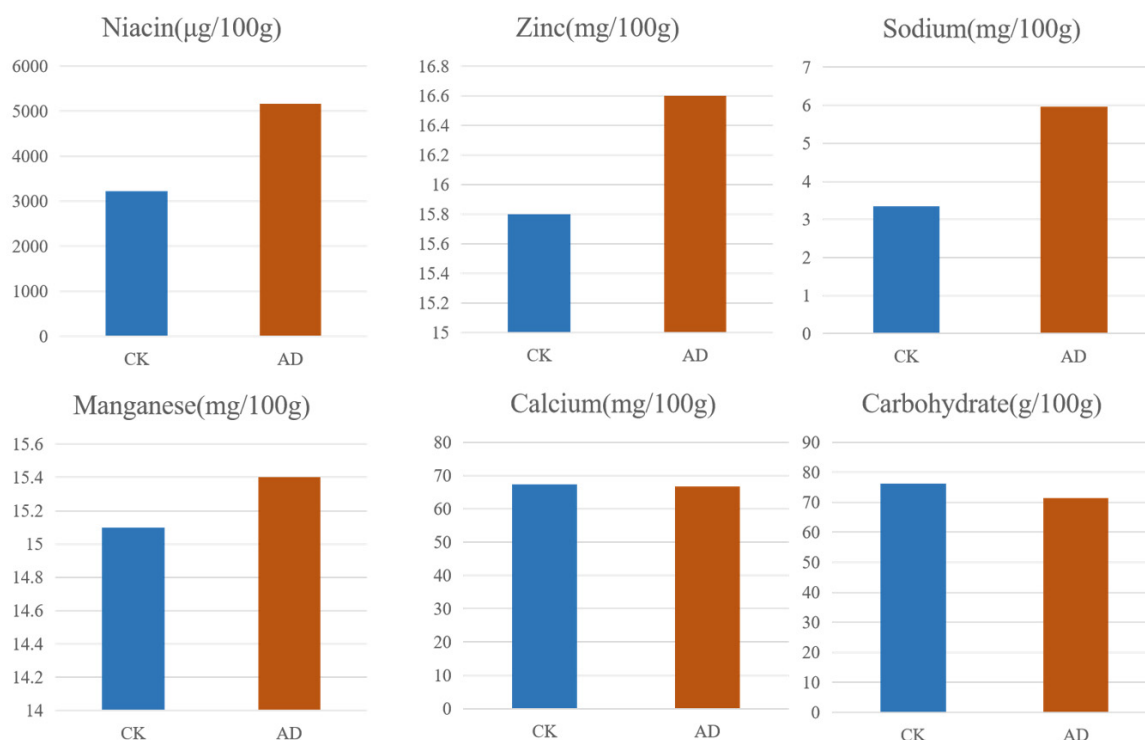


Fig 7. Trace elements and nutrients in rice

Zinc is one of the essential micronutrients for plants and a nutrient essential for human health. Zinc deficiency will affect the growth and development of plants, resulting in reduced yield and quality of plants. At the same time, zinc has a variety of physiological effects on the human body [27], and zinc is one of the important elements affecting mental development and psychological quality. Zinc deficiency can affect visual function, resulting in decreased vision, as well as mental development, resulting in decreased memory and anorexia [28]. Zinc also aids in pregnancy, as well as in child and adolescent development [29]. From Fig 7, it can be found that by plasma treatment the zinc content of rice can be increased by 0.8 mg/kg, i.e. increase by 5.06%.

Sodium promotes the growth of saline-soil plants by regulating osmotic pressure of plants, and can affect plant water balance and cell extension [30]. In the human body, the main role of sodium is as the main positively charged ion in the extracellular fluid. Sodium participates in the metabolism of water and maintains the balance of acid and alkali in the paste, which is a necessary element for the contraction of soft tissues [31]. According to Fig 7, sodium content of plasma treated rice is 2.63 mg/kg, increasing by 78.74%.

Manganese promotes bone development. If the human body lacks trace element manganese, it will cause symptoms such as decreased brain function and low reproductive ability. Calcium is an indispensable trace element in human body and one of the most abundant minerals. Calcium is an important component of teeth and bones and plays an important role in regulating the normal functioning of various systems, tissues and organs in the body. Adequate calcium can maintain high energy, inhibit abnormal excitation of brain nerves and improve people's thinking ability. Carbohydrates are composed of carbon, hydrogen and oxygen. They mainly provide energy, save protein, maintain the function of brain cells and resist ketone bodies. As shown in Fig 7, manganese

content of plasma treated rice is 0.3 mg/kg (increasing by 1.9%), the calcium content is basically the same as that in control group, the carbohydrate content of plasma rice is slightly lower than that of control group, without significant difference. These results show that plasma treatment can adjust the nutrients of rice. From the perspective of application, plasma treatment on rice can be carried out according to the needs of nutrients.

4. Conclusion and Discussion

This article presents the effect of plasma treatment on the growth, yield, and nutrients of rice. It shows that the optimized plasma treatment of seeds is beneficial to the growth of rice so that to increase production and improve quality. The correlations between plasma treatment time, rice growth parameters and yield were also analyzed, indicating the strong correlation between yield and tillering number and the extremely strong correlation between the tillering number and the height of rice.

This study presents the field planting results of plasma treatment in rice crop and can provide some help for the popularization and application of plasma agriculture.

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