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Effect of low-temperature plasma on forage maize (*Zea mays Linn.*) seeds germination and characters of the seedlings

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Abstract. Low-temperature plasma is a high-energy state of the material gathered. Plasma seed processing technology is the use of high energy aggregation on treating crop seeds within 20 seconds. Previous research elucidated that this technology could improve germination and seedling growth of welsh onion seeds. In this paper, the effects of different intensities of low-temperature plasma on forage maize seeds have been investigated. The vigor and rate of germination, length of root and shoot of seedlings, the green and dry weight, and the fiber root number of seedlings of the treated sample seeds were compared with those of untreated seeds. The results showed substantial changes in the vigor and rate of germination just like what we found in welsh onion seeds. Thus, the characters of seedlings change regularly with the intensity of low-temperature plasma, and the analysis indicated that 120W was the optimum treatment. Results showed that low-temperature plasma was effective in improving seedling growth, we believe it will be also effective in earlier flowering and maturity and higher yield. There is a great value of using and spreading on production.

Key words: Low-temperature plasma; forage maize seeds; characters of seedlings

1. Introduction

Besides the ‘traditionally’ known solid state, liquid and gas phase and the more recently found low-temperature states (BOSE-EINSTEIN condensate), high-temperature states, such as plasmas existing. Although the generation of a plasma from the gas phase (Figure 1) isn’t strictly spoken to be a real phase transition, plasma was recognized as the 4th state of matter due to its distinct properties, which substantially discriminated it from the gas phase[1].

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Physical agriculture is the application of physical methods in agriculture and has been studied since the 1970s[2]. Low-temperature plasma (LTP) is an application of physical agriculture. Yin (2006) reported that LTP was utilized in biological applications in Russia[3]. There has been some research in LTP seed processor comprising a plasma generator was used to treat seeds in Russia and CIS countries (Li, 2010). Similar reports exist in America and Canada[4]. Stimulation of plants with a plasma field to promote seed germination and increase yield quantities and quality has attracted interest worldwide, with remarkable achievements reported in Japan[5]. At present, abroad study shows that both ionizing radiations, and even mass loading effect and exchange of charge are existing in LTP field. This field activated endogenous substances in the seeds, leading to improvements in the rate of seed germination, crop resistance and crop yield and an earlier maturity date[6-11].

\textit{Zea mays} Linn., maize or corn, is one of the major cereals of the world and is the third largest field crop. Various kinds of technology have been used on maize seeds processing to promote germination and increase yield, such as magnetization and plasma[12-13]. Our study focuses on the influence of LTP treatment on maize seeds in terms of the seed germination and biological characters of seedlings.

2. Materials and Methods

2.1 Experimental set-up

The equipment used in this study was provided by ChangZhou ZhongKe ChangTai Plasma Technology Co. and
the device worked under the vacuum state. This machine can be carried out with large capacity in a continuous or batch process.

2.2 Sample seeds

Tests were carried out both in laboratory and field conditions with LUZHONG 99118 maize seeds (selected by Shandong Province Seeds Group Co., LTD). This variety is food and fodder dual-purpose maize. There still have 12 to 13 green leaves when maturing, suit to be used as silage.

2.3 Experimental design

2.3.1 Test media

Laboratory plasmas can be generated by supplying energy to a kind of neutral gas. Electrical discharges are the most common for generating non-thermal plasmas. Neon is colorless and odorless inert gases. Neon conducts electricity 75 times better than air. The test result indicates a uniform stable glow discharge has been obtained between two planar electrodes when using neon as test media. Therefore, neon was used as media in our experiment.

2.3.2 LTP treatment

Healthy and uniform maize seeds were treated with various plasma strengths (0, 60, 80, 100, 120, 140, 160, 180, 200W). 1 kilogram of maize seeds was used in each treatment.

2.3.3 Germination tests and analysis of the germination rate, vigor

The germination tests were started on the 16th, 30th, 45th, 60th, 75th, 90th, 120th, 150th days after seeds treated by LTP. Each treatment was repeated four times to confirm the repeatability of the results, with 100 seeds for every repetition.

After treatment, the seeds were allowed to germinate in sand bed under laboratory. During the experiments, water was added to the sand bed to guarantee sufficient moisture for germination. The incubation temperature was 25°C.

A seed was considered germinated if both the radicle and coleoptile length were \( \geq 2 \) mm. Seedlings were counted at 24-h intervals up to 7 days. The germination vigor is used to assess the quality of field emergence and is defined as the percentage of seeds that germinate within a short time (4 days after lined for maize according to GB/T 3543.4-1995, Rules for Agricultural Seed Testing-germination test). The germination rate is defined as the
percentage of seeds that germinate in a specified time (7 days after lined for maize according to GB/T 3543.4-1995). These are calculated as follows:

Vigor of germination (%) = \(\frac{\text{Number of seeds germinated in 4 days}}{\text{total number of seeds}} \times 100\)

Rate of germination (%) = \(\frac{\text{Number of seeds germinated in 10 days}}{\text{total number of seeds}} \times 100\)

2.3.4 Investigation on biological characters of maize seedlings in laboratory

On the 7th day of germination experiment, ten seedlings of each repetition were randomly selected and the length of shoot & root, green & dry weight of these seedlings were investigated. Length of shoot is defined as the length between the mesocotyl and tip of seedlings. Length of root is defined as the length between the mesocotyl and the root tip.

Samples used in this experiment were kept in a cool dry place for 90 days after treated by LTP. Also, both the green and dry weight of seedlings were measured.

2.3.5 Investigation on biological characters of maize seedlings in field

In 90 days after treated by LTP, seeds were sowed in field. Ten days later, ten seedlings of each repetition were randomly selected and the length of shoot & root, fiber root number were investigated.

3. Results and Discussion

This experiment was conducted to assess the influence of different intensities of LTP on seed germination and early growth, also the aging effect of this influence was investigated. The data of germination vigor for maize seeds are listed in Table 1, and the data of germination rate are listed in Table 2.

The optimum intensity of samples in different times after LTP treated is fugitive. But for each samples, we can both have the maximal vigor and rate in one certain intensity.

The effect of LTP on vigor and rate of maize seeds germination changed with time. LTP played an active role in seed germination within 16 days. And it dropped the seed germination rate and vigor during 30-120 days, 150 days after treated, and this inhibition had been weak.

Table 3 showed the shoot and root length of seedlings under lab condition, and the shoot & root length and fiber root number of seedlings in field were lined in table 4. The green and dry weight of seedlings in field were listed in table 5.
Table 1. Vigor of germination of forge maize seeds stimulated by low-temperature plasma（%）

| Intensity of LTP (W) | 0 (ck) | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 |
|---------------------|-------|----|----|-----|-----|-----|-----|-----|-----|
| Days after treatment |
| 16                  | 81b   | 88a| 89a| 91a | 91a | 88a | 88a | 87a | 87.83ab |
| 30                  | 82d   | 86bcd| 86bc| 87bc | 90abc | 90abc | 92a | 86cd | 91ab | 88.06ab |
| 45                  | 81b   | 91a | 89a | 86a | 89a | 88a | 82a | 90a | 87a | 88.17a |
| 60                  | 81b   | 91a | 89a | 86a | 89a | 87a | 87a | 89a | 87a | 87.22ab |
| 75                  | 81d   | 88abc| 91ab | 92a | 86bc | 86c | 85cd | 84cd | 87bc | 86.44b |
| 90                  | 80c   | 89a | 86ab | 86ab | 91a | 88a | 88a | 83bc | 88a | 86.44b |
| 120                 | 75d   | 80cd| 81bc | 84ab | 86a | 80bc | 86a | 81bc | 78cd | 80.33c |
| 150                 | 74cd  | 76abc| 75bcd| 79a | 81a | 80a | 79ab | 81a | 71d | 77.11d |
|                    | 78.94e| 85.5bcd| 85.75abcd| 87ab | 87.38a | 86.13abc| 87.06ab | 84.81cd | 84.25d | / |

Note: Columns with different lowercase letters: Low-temperature plasma treatment on Alexander Summer Squash bud potential, germination rate, significant differences in germination index (P ≤ 0.05)

Table 2. Rate of germination of forge maize seeds stimulated by low-temperature plasma（%）

| Intensity of LTP (W) | 0 (ck) | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 |
|---------------------|-------|----|----|-----|-----|-----|-----|-----|-----|
| Days after treatment |
| 16                  | 93c   | 94bc| 94bc| 96ab | 96a | 94bc | 95ab | 96a | 93c | 94.22a |
| 30                  | 93ab  | 92b | 93ab | 92b | 94ab | 92b | 95a | 94ab | 92b | 92.72bc |
| 45                  | 93bcd | 93bcd| 94abc| 91d | 95a | 93bcd | 94ab | 92cd | 92cd | 92.79b |
| 60                  | 93ab  | 93ab | 92abc| 91bc | 90c | 93ab | 93ab | 94a | 91bc | 92.18cd |
| 75                  | 93ab  | 94a | 94a | 91b | 93a | 93a | 94a | 93ab | 92ab | 92.83b |
| 90                  | 93abc | 92c | 92abc| 93abc| 91c | 92c | 93ab | 93a | 93ab | 92.33bc |
| 120                 | 94a   | 92abc| 93a | 93ab | 94abc| 91abc | 92ab | 92abc| 90bc | 92.11cd |
| 150                 | 92abc | 94ab | 92abc| 92bc | 91c | 91c | 94ab | 94a | 91c | 92.06cd |
|                    | 92.56ab| 92.68ab| 92.87ab| 92.75ab| 92.69ab| 92.13bc| 93.25a| 93.25a| 91.63c | / |

Note: Columns with different lowercase letters: Low-temperature plasma treatment on Alexander Summer Squash bud potential, germination rate, significant differences in germination index (P ≤ 0.05)

Table 3. Length of shoot and root of seedlings under laboratory condition stimulated by low-temperature plasma（%）

| Intensity of LTP (W) | 0 (CK) | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 |
|---------------------|-------|----|----|-----|-----|-----|-----|-----|-----|
| Length of shoot (cm) 10.99cd | 11.52bc | 12.04ab | 12.13ab | 12.3a | 11.50bc | 11.65bc | 11.36cd | 10.74d |
| Length of root (cm) 19.11bc | 19.55abc | 20.82a | 20.14ab | 19.33bc | 19.12bc | 19.40bc | 18.98bc | 18.19c |

Note: Columns with different lowercase letters: Low-temperature plasma treatment on Alexander Summer Squash bud potential, germination rate, significant differences in germination index (P ≤ 0.05)
Table 4. Length of shoot and root and fiber root number of seedlings under field condition stimulated by low-temperature plasma (%)

| Intensity of LTP (W) | 0 (CK) | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 |
|----------------------|--------|----|----|-----|-----|-----|-----|-----|-----|
| Length of shoot (cm) | 10.21cd | 10.14d | 10.33cd | 11.42ab | 12.04a | 11.95ab | 11.62ab | 10.75bc | 11.03ab |
| Length of root (cm)  | 31.04a  | 36.55a | 35.53a | 34.57a | 33.05a | 33.04a | 36.07a | 36.9a  | 35.01a |
| Fiber root number    | 4.4ab   | 4b  | 4.6ab | 4.75ab | 5ab  | 5.2a  | 4.6ab | 4.6ab | 4.5ab |

Note: Columns with different lowercase letters: Low-temperature plasma treatment on Alexander Summer Squash bud potential, germination rate, significant differences in germination index (P ≤ 0.05)

Table 5. Green and dry weight of seedlings stimulated by low-temperature plasma (%)

| Intensity of LTP (W) | 0 (CK) | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 |
|----------------------|--------|----|----|-----|-----|-----|-----|-----|-----|
| Green weight (g)     | 83.04cd | 81.83d | 85.77cd | 91.62ab | 95.10a | 95.70a | 87.96bc | 83.47cd | 83.46cd |
| Dry weight (g)       | 12.52bc | 12.44bc | 12.21cd | 12.69bc | 13.00a | 12.75ab | 12.55bc | 12.76ab | 12.45bc |

Note: Columns with different lowercase letters: Low-temperature plasma treatment on Alexander Summer Squash bud potential, germination rate, significant differences in germination index (P ≤ 0.05)

90 days after seeds treated by LTP, almost all the intensities (60 -200W) could increase the shoot & root length, green & dry weight and the fiber root number also increased.

It is clear that in the case of an ordinary plant leaf area will increase as growth proceeding, and with increasing leaf area the rate of production of material by assimilation will also increase, this will also lead to higher yield. LTP treatment has a great value of using and spreading on crop production, and the optimal treatment intensity for forage maize seeds was 120W.

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