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Promoting Lentil Growth by Alkaline Plasma-Activated Water (APAW)

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Alkaline, plasma, lentil, water

A B S T R A C T

Cold atmospheric plasma as a source of active species like nitrite, nitrate, and hydrogen peroxide is an emerging technology in agriculture that applies these energetic and reactive species to improve the germination and growth of crops. The present study aims to give the results of using alkaline plasma-activated water containing active species including nitrite, nitrate, and hydrogen peroxide produced by plasma electrolysis to improve the germination and growth of lentils. Germination was surveyed by soaking the seeds in two samples with tap water and alkaline plasma-activated water. The ability of seeds to germinate was higher in alkaline plasma-activated water samples than in tap water samples. Investigation of growth was done in two irrigated with tap water and alkaline plasma-activated water samples. The growth of alkaline plasma-activated water sample was higher than the tap water sample. As a result, APAW can be used in cases where alkaline conditions rich in reactive species are needed.

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مقاله پژوهشی

بررسی ماندگاری بصری میوه آلو پوشش داده شده با نانوذرات بیوسنتز شده با پلاسما

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چکیده

Cold atmospheric plasma as a source of active species like nitrite, nitrate, and hydrogen peroxide is an emerging technology in agriculture that applies these energetic and reactive species to improve the germination and growth of crops. The present study aims to give the results of using alkaline plasma-activated water containing active species including nitrite, nitrate, and hydrogen peroxide produced by plasma electrolysis to improve the germination and growth of lentils. Germination was surveyed by soaking the seeds in two samples with tap water and alkaline plasma-activated water. The ability of seeds to germinate was higher in alkaline plasma-activated water samples than in tap water samples. Investigation of growth was done in two irrigated with tap water and alkaline plasma-activated water samples. The growth of alkaline plasma-activated water sample was higher than the tap water sample. As a result, APAW can be used in cases where alkaline conditions rich in reactive species are needed.

کلیدواژه‌ها

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I. INTRODUCTION

Lentil (Lens culinaris Medik) is one of the olden food crops that is an important crop in the farming systems of West Asia and North and East Africa [1]. The lentil is a softly pubescent, light green annual herbaceous plant that is much-branched and has a slender stem and branches. The lentil plant life cycle is continuous. It begins with seed germination and finishes with complete seed maturation. The lentil is grown under widely differing ecological conditions. Lentil has a different branching habit than the other food legumes [2-3]. Lentil flowering is undetermined, occurring from axillary buds on the main stem and branches acropetally from lower to higher nodes [4].

Optimizing the selection of the right product, the manner of preparing the soil, fertilizing, pesticide usage, and irrigation are ways to improve product performance in traditional methods. These methods are not always effective and can be influenced by many factors, such as weather and environmental cultivation conditions [5-6]. The application of cold or non-thermal plasmas (NTPs) technology in agriculture, including water and wastewater treatment, soil treatment, pest control, and pre-planting seed modification, is introduced as a new multidisciplinary research fields based on the interaction of NTP with agriculture crops directly or indirectly [7-13]. Nowadays, the use of NTP in agriculture has provided a new way to improve the germination and growth performance of plants, as a fast, low-cost, green, and risk-free method, with the possibility of making plasma reactors with more efficient, smaller, and cheaper power supply [14]. In this approach, reactive oxygen and nitrogen species (RONS) produced by plasma can mainly improve germination and growth through direct interaction with the seed surface or through water activated by plasma containing these species [15]. Brist et al. first introduced the concept of liquid activation by plasma [16]. Plasma-activated water (PAW) is obtained from tap, distilled, or demineralized water exposed to interaction with plasma in a vacuum environment or atmospheric pressure with different reactor configurations [17]. It has been reported that PAW has a lower pH, higher conductivity, and higher oxygen reduction potential than untreated water due to the presence of reactive species [18].

In recent decades, the use of cold plasma in food and agriculture has developed. It attracted the attention of many researchers and food industry owners. Many reports have presented the effect of PAW on plant growth [19-22]. However, no information about activated water by plasma with alkaline properties has been reported to improve the growth of crops. This research was done to study the advantages of cold plasma capacity in germination and growth of lentils by alkaline plasma-activated water (APAW) produced by oxygen-nitrogen plasma electrolysis. The characteristics of the produced plasma and the effects of APAW on germination and growth were described. Nitrite (NO_2^-), nitrate (NO_3^-), and hydrogen peroxide (H_2O_2) synthesized in water resulting from the plasma interaction with the water surface were displayed by visible-ultraviolet spectrophotometer (UV-Vis), ion chromatography, and hydrogen peroxide test strip. Their effects were reported on germination and growth. The parameters of electron temperature (T_e) and density (n_e) of oxygen-nitrogen plasma were determined by emission spectroscopy.

II. MATERIALS AND METHODS

According to Figure 1, a Pyrex glass symmetrical H-shaped reactor was used. It included two 200ml tubes connected by a connector with an external diameter of 20mm. The Whatman filter paper was used inside the connector to prevent water from mixing inside the two tubes. The reactor was filled with distilled water (DW). The cathodic side of the reactor tube was placed on a magnetic stirrer so that the interaction of the plasma with water was done homogeneously. The reactor electrodes were selected tungsten rods with a 2mm external diameter. The anode electrode was immersed in the water on the anode side. The cathode electrode inside the T-shaped glass tube with a 2mm distance outside its end was placed on the water surface on the cathode side. The mixture of oxygen and nitrogen gases was passed around the cathode inside the T-shaped glass tube. The gas flow rate was set at 40sccm. Plasma was produced in a 2mm discharge gap between the tip of the cathode and the water surface. The plasma exerting time on the water surface was 5min. The power supply was a high-voltage direct current (DC) adjusted at about 7.5kV.

The synthesis of NO_2^- and NO_3^- anions in the liquid phase was confirmed by a UV-Vis spectrophotometer (Specord 250) manufactured by Analytik Jena in the wavelength range of 200-800nm. The concentration of ions measured by ion chromatography (930 Compact IC Flex, 150mm version of the Metrosep A Supp 5 - 150/4.0) made by Metrohm with a particle size of 5µm. The synthesis of H_2O_2 was evaluated with a hydrogen peroxide test strip (0.5-2-5-10-25 mg/liter) of Hangzhou Lohand Biological Company. Emission spectroscopy of oxygen-nitrogen plasma was performed by TIDA spectrometer (UCS-G400) in the wavelength range of 200-1000nm manufactured by Teksan.

The germination test was carried out in a random arrangement with a 20gr population in two different samples. The seeds in two samples were soaked with tap water (TW) and APAW for the germination test.

The growth test was done in a random arrangement with a 30gr population in two different samples. The seeds were soaked with APAW and planted in the soil three days after soaking. Two samples were irrigated with TW during the test. Five days after planting, one of the samples was irrigated with APAW instead of TW. The germination and growth tests were done in laboratory environmental conditions.

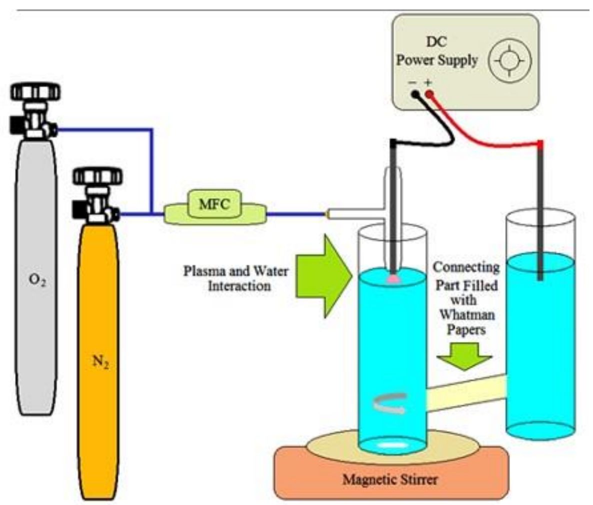

Figure **1.** The reactor of the production and interaction of oxygen-nitrogen plasma with the water surface.

III. Discussion

The emission spectrum of oxygen-nitrogen plasma resulting from interaction with the water surface was used to obtain plasma electron temperature and density. The plasma electron temperature was calculated via the Boltzmann plot method. The plasma electron density was determined using the Stark broadening of H_β. The required relations are shown in Table 1 [23].

Figure 2 shows Boltzmann plots of N I and O I spectral lines and typical Voigt-function fitting of the experimental profile for H_β oxygen-nitrogen plasma.

Table 1. Formulas for calculation of plasma electron temperature and density.

Plasma parameters	The Formulas	Formula components
Plasma electron temperature	$\ln\frac{I_{ji}\,\lambda_{ji}(nm)}{A_{ji}(s^{-1})g_j} = -\frac{E_j(eV)}{k_B T(eV)} + C$	I_{ji} : The intensity of the spectral line λ_{ji} : The wavelength of the emitted light A_{ji} : The transition probability g_j : The statistical weight of the energy level E_j : The energy level of the upper state for emission k_B: Boltzmann constant T : Plasma electron temperature C : Constant value
Plasma electron density	$\Delta\lambda_{stark} = 4.8(nm)\left(\frac{n_e}{10^{23}}\right)^{0.68116}$ $\Delta\lambda_{stark} = \Delta\lambda_{Lorentz} - \Delta\lambda_{Vander\ Waals}$ $\Delta\lambda_{Vander\ Waals} = (3.6)\left(\frac{P(atm)}{T_g^{0.7}(K)}\right)$	P = 1atm T = 300K $\Delta\lambda_{Lorentz}$: Estimating by the fitting of experimental spectra with the Voigt profile

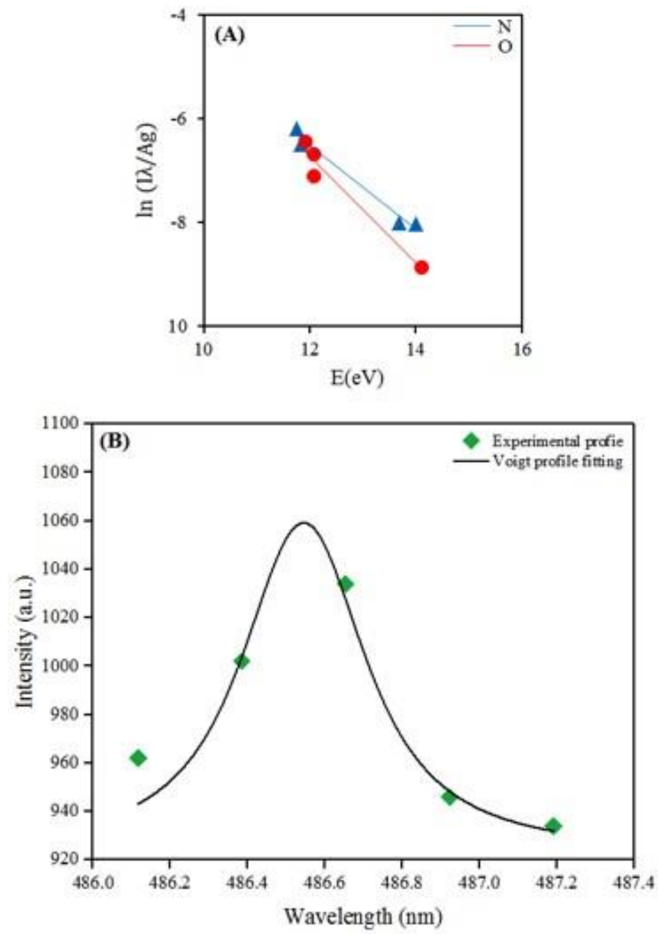

Figure **2.** (A) Boltzmann plots of N I and O I spectral lines and (B) typical Voigt-function fitting of the experimental profile for H_β oxygen-nitrogen plasma.

Table 2 displays Atomic data of selected N I and O I lines [24]. The average electron temperature of oxygen-nitrogen plasma was 1.105 eV. The plasma electron density was calculated $n_e = 1.530 \times 10^{21} m^{-3}$.

Table 2. Atomic data of N I and O I lines.

	Wavelength (nm)	Transition Probability ($10^8 s^{-1}$)	Statistical Weight	Upper Level Energy (eV)
N I	874.737	1.04	4	11.7529
	824.239	1.36	4	11.83971
	731.898	5.41	4	13.693574
	395.3486	4.47	4	13.998826
O I	1131.651	2.38	3	11.930287
	926.094	1.56	5	12.078545
	920.49	1.66	7	12.086939
	395.3486	3.09	9	14.123702

Due to the aim of this research, two parts of anode and cathode were considered separately in the designed reactor. Plasma activated water (PAW) on the anode side and alkaline plasma activated (APAW) water on the cathode side were obtained after interacting oxygen-nitrogen plasma with water by plasma electrolysis. APAW on the cathode side was chosen for the test. pHs and electrical conductivities (EC) of TW, DW, and APAW used in tests are shown in Table 3. According to the data in the Table 3, pH and EC of DW used in the reactor has increased after interacting with the plasma on the cathode side in soaking and irrigation modes.

Table 3. pHs of DW, TW, and APAW to soak and irrigate.

Type of water	pH	EC(μS/cm)
TW (soaking)	6.86	111
DW (soaking)	6.99	2
APAW (soaking)	7.65	58
TW (irrigation: 0th day)	6.82	123
TW (irrigation: 2th day)	6.86	115
TW (irrigation: 5th day)	6.80	127
DW (irrigation)	7.02	3
APAW (irrigation)	7.74	64

Figure 3 displays the UV-Vis spectrum of DW, TW, and APAW in germination and growth tests. The absorption peaks of APAW were observed in the 200-210 nm range. The absorption peaks of nitrite and nitrate anions have been reported in this range [25-26]. TW and DW lacked peaks. The results of ion chromatography confirmed the synthesis of NO_2^- and NO_3^- after plasma interaction with the water surface. The concentrations of NO_2^- and NO_3^- anions were in the range of 4-7ppm and 2-4ppm, respectively. The concentrations of H_2O_2 was approximately 0.5ppm and less. DW and TW with a pH in the neutral range did not contain NO_2^--, NO_3^- and H_2O_2.

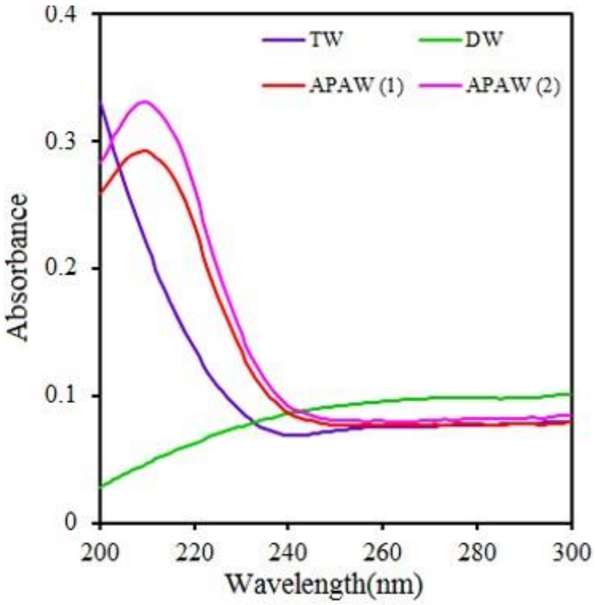

Figure **3.** Absorption spectra of DW, TW, and APAWs used for the germination and growth [APAW(1): used for soaking, APAW(2): used for irrigation].

Figure 4 shows the effect of APAW on lentil germination and growth. As can be seen, the volume of germinated seeds in the sample soaked with APAW was greater than that of the sample soaked with TW. The growth of the sample irrigated with APAW was higher than sample irrigated with TW. It is inferred that the APAW, contain of NO_2^- and NO_3^-, and H_2O_2, can be highly useful for germination and growth of lentin.

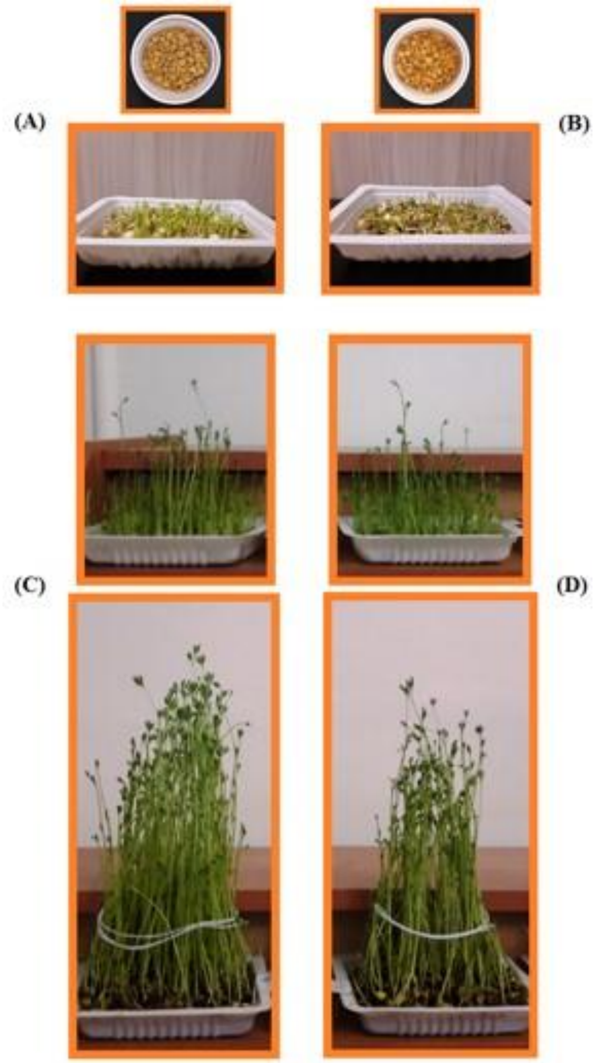

Figure **4.** Germination with (A) APAW and (B) TW and Growth with (C) APAW and (D) TW.

IV. Conclusions

Considering that there is no information about alkaline plasma-activated water in improving crops, an investigation was made in this regard. In this research, the oxygen-nitrogen plasma was interacted with the water surface by plasma electrolysis method. Water was simultaneously produced with two acidic properties (PAW) on the anode side and alkaline properties (APAW) on the cathode side. APAW was selected for investigation. Its effect on the germination and growth of lentils was reported. According to the results, the germination and growth of samples soaked and irrigated with APAW were more than TW samples due to reactive species of NO_2^-, NO_3^-, and H_2O_2. APAW had a high pH value, conductivity, nitrite, nitrate, and hydrogen peroxide concentrations than DW. As a result, APAW can be used in cases where alkaline conditions rich in reactive species are needed.

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