Effects of air plasma treatment on water uptake of wheat and barley seeds

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ABSTRACT
In this study, radio-frequency (RF) plasma was used to treat the surface seeds of wheat and barley. Plasma treatment was conducted for different exposure times (1, 5, and 10 min) and at different powers (20, 50, 80 and 100 W), keeping the air gas pressure fixed at 1.0 torr. It was observed that the seeds that were exposed to 80 W of plasma power for 10 min exhibited a higher water absorption rate. The weight gain of the treated wheat and barley seeds was increased by 62% and 12%, respectively, compared to the control sample (untreated seeds). Spectroscopic and microstructural analyses of the seed surface indicated that the plasma treatment caused chemical etching, which improved the water uptake of the treated seeds.

1. Introduction
The impact of seed treatment with radiofrequency plasma has been extensively investigated over the past two decades [1,2]. Systematic studies have demonstrated the impact of plasma on different seed species and revealed a significant improvement in germination rates compared to untreated controls [2–4]. Generally, researchers have focused on the following research methods: (i) plasma seed decontamination, (ii) plasma dormancy breakdown, (iii) germination of treatment seeds, and (iv) the effect on root generation (sprouting) [5].

The results of a recent study proved that plasma treatment leads to the formation of new features on seed surfaces, surface variation due to charged particles, and neutral radicals in the plasma. The experimental results indicate that the surface composition changes with the formation of polar groups. These groups initiate a shift in the surface characteristics from hydrophobic to hydrophilic properties [6,7].

The germination process, creation of biomass, utilized power for the case of seedlings, and water uptake have been investigated in wheat seeds treated with atmospheric plasma [8–10]. These studies indicate an increase in the dry weight and water uptake of plasma-treated seeds compared to untreated seeds. Increased exposure to plasma also results in increased water absorption [3,11].

In another study, the effects of plasma treatment on the growth parameters of wheat, such as the length of the roots and sprouts and the dry weight, were measured. The roots and shoots of the seeds treated with plasma had a higher weight than the control samples [2,12–15].

On the other hand, plasma treatment resulted in a significant improvement in water absorption of seeds, measured by the weight gain after soaking, compared to seeds were not treated with plasma. The increase in the absorption of water can cause a partial degradation of cellulose and the formation of cracks in the outer cell layer [16,17].

However, the reasons for these observed differences after plasma treatment have not been extensively determined [18–20].

The aim of this study, is to investigate the effects of RF-low pressure low-power plasma treatment on wheat and barley seeds to improve water uptake processes under different plasma conditions, such as the power and exposure duration time of the RF-plasma. To study the effect of the RF plasma treatment applied to the surface on the functional groups of wheat and barley seeds, FTIR spectroscopy (IRAffinity-1S, Shimadzu, Japan) was used. Also, scanning electron microscopy (SEM) (JSEM 7400F, Joel, Japan) measurements were performed to study the changes the surface morphology of plasma-treated seeds before and after RF plasma treatment.

2. Material and methods
In this study, locally grown wheat and barley seeds were used.

Eight groups of each type of seed (wheat and barley) were used, consisting of 80 seeds of wheat and 105 seeds of barley. Three groups were exposed to air RF-plasma at 80 W for 1, 5, and 10 min, and four groups were exposed to RF plasma power of 20, 50, 80, and 100 W, for 10 min. A control sample was left untreated.
Each group was weighed after treatment and placed in 20 ml of distilled water for 24 h to induce water uptake. The seeds were removed from the water every 3 h, air-dried on a piece of paper, and then weighed immediately after the surface was dried. The weight gain percentage was calculated using the following equation [21]:

$$\text{Weight gain (\%)} = \frac{W_{after} - W_{before}}{W_{before}} \times 100 \quad (1)$$

where $W_{before}$ and $W_{after}$ represent the weights of seeds before and after water uptake, respectively.

3. Experimental setup

The plasma-generating chamber was cylindrical in shape and made of stainless steel, 25 cm in diameter and 36 cm in height. It contained two parallel plates of stainless-steel electrodes with a diameter of 5 cm and a distance of 2.5 cm between them. The two electrodes were placed inside dielectric ceramics and were connected with an RF power supply and impedance-matching network. The lower electrodes were powered by an RF source (type ENI model OEM-6, 13.56 MHz and 0–200 W power), whereas the upper anode was connected to the ground. A rotary pump brought the chamber to a base pressure of $10^{-4}$ torr. The air gas pressure was fixed at 1.0 torr and maintained at this value during all measurements.

Figure 1 shows the experimental setup used to generate the RF plasma.

4. Results and discussion

Cold plasma is used in various industrial applications, including seed treatment, to improve water absorption and address irrigation-related problems.

The effects of the two different RF plasma parameters, namely, plasma treatment times and RF power, on the surface seeds of wheat and barley were investigated. In this work, the seeds were treated by air RF plasma with four different discharge powers (20, 50, 80 and 100 W) and in three different exposure times (1, 5 and 10 min).

4.1. Water uptake measurements.

Figure 2 shows the relation between the water uptake duration versus weight gain % of wheat seeds at various plasma power levels.

An improvement in the weight gain of wheat seeds treated with the plasma power of 80 W, compared with the seeds treated at plasma powers of 20, 50, and 100 W. The wheat seeds treated at a plasma power of 80 W for 10 min showed a weight gain improvement of 62%, compared to the control. The seeds treated with RF-powers of 20, 50, and 100 W displayed a weight gain improvement of 46%, 45%, and 48%, respectively [22].

Also, Figure 3 shows an increased in weight gain of wheat seeds treated using plasma at power of 80 W for 10 min compared to the seed samples treated at the same power for 1 and 5 min. The wheat sample groups treated at 80 W for 1, 5 and 10 min showed an increase in the weight gain corresponding to 50%, 43%, and 62% respectively, compared to the control.

Moreover, Figure 4 shows the water uptake duration versus weight gain % of barley seeds at various plasma powers. The barley sample group treated at 80 W showed a greater increase in the weight gain (12%) compared to the other samples treated at different plasma powers (20, 50, and 100 W). The results confirmed that the barley seeds treated with plasma absorbed more water than the control seeds.

On the other hand, the experimental results demonstrate that the water uptake of the wheat seeds at a plasma power of 80 W increased significantly compared to the barley seeds. This is possibly due to the difference in the surface morphology of the seed coat and the thickness of the endosperm of the wheat seed compared to that of the barley seed [21].

Figure 5 shows the water absorption rate of the barley seeds, which were treated at different exposure times (1, 5, and 10 min) at plasma power of 80 W. The water uptake increased by approximately 12% for the sample treated for 10 min compared to the control, and approximately 7 and 6% for the other treated samples. The results of this study were in agreement with that of previous studies and demonstrated that plasma treatment could promote water uptake [10,23].

Air plasma is practical and produces a rich chemistry. So, if the seed is rather permeable, it may functionalize the surface through the addition of chemical groups on the surface to become more hydrophilic and enhance gas exchange to then affect the seed biochemistry, which increase the water absorption rate of the seeds [6].
Many authors reported evidence, more often than not, that plasma treatment modifies the seed surface in such a way that water uptake increases; this is either done by poration, removal of the topmost layers or through oxidizing the surface to improve the water interaction. It is not yet clear whether it is through mechanical, chemical means or both and whether this is dependent on the plasma treatment, seed type or both [9].

4.2. Fourier transforms infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy is an important technique for studying the spectral characteristics of the treatment surfaces of seeds by classifying the molecular function groups. This technique was used to determine the characteristics of the reactive species produced during plasma treatment and
their effect on the germination of different types of seeds [16,20,24].

The seeds were treated using a plasma power of 80 W for 10 min, and the results were compared with the FTIR spectra of the untreated seeds. The sample pellets were made of potassium bromide and wheat/barley seed powder to obtain the spectral transmittance in the range of 300–4000 cm$^{-1}$ [25,26].

The FTIR spectra of the treated wheat seeds using a plasma power of 80 W for 10 min and the control sample are shown in Figure 6. The fundamental absorption bands are due to the stretching vibration of the hydroxyl group (OH), which appears as a broad band in the range of 3000–3610 cm$^{-1}$. The stretching vibration of the aliphatic hydrogens was recorded at approximately 2950 cm$^{-1}$, whereas the absorption
bands observed at 1000 and 1150 cm\(^{-1}\) were attributed to the C–O acyclic and C–O–C cyclic bonds, respectively. A moderate absorption was also observed at 1650 cm\(^{-1}\) and assigned to the C = O group. The investigation of the two IR spectra of the untreated and treated wheat did not reveal any changes in the absorption bands resulting from the plasma treatment.

Figure 7 shows the FTIR spectra of the untreated barley seed and that of the treated seed at a plasma power of 80 W for 10 min. The results show the same absorption bands to 3000 cm\(^{-1}\) (C–O: 1125 cm\(^{-1}\); C–O–C: 1325 cm\(^{-1}\); C = O: 1670 cm\(^{-1}\)). The hydroxyl group (OH) of the untreated seed was observed between 3000–3750 cm\(^{-1}\) as an extremely broad band, whereas
the same hydroxyl group was observed at approximately 3000 and 3580 cm\(^{-1}\) with low broadness and intensity for the treated seed. This is probably because the plasma reduced the excitation of the hydrogen bonds of the molecules [9,27].

4.3. Scanning electron microscopy (SEM)

The effects of the plasma treatment on the morphological surface characteristics of the seeds were examined using SEM images of the wheat and barley seeds that were treated using RF-plasma at a power of 80 W for 10 min.

Figures 8 and 9 compare the morphological structures of the treated and untreated seed surfaces using SEM images. Microstructural analysis confirmed the surface changes observed in the SEM image after plasma treatment. The peeling and etching of the seed walls were evident in the SEM images, which led to higher absorption of water [28]. Also, SEM images show the appearance of particular structure on the treated seed surface.

5. Conclusions

The influence exerted by cold radiofrequency (RF) plasma treatment on wheat and barley seeds was investigated. The plasma treatment of the wheat and barley seeds exhibited a maximum increase in the water uptake at a plasma power of 80 W for 10 min. Increases in the weight gain of 62 and 12% were observed for the treated wheat and barley seeds, respectively, compared to the control samples.

The structural changes of the seed surface due to plasma treatment were analyzed using FTIR spectra. SEM analysis revealed that longer exposure to the plasma resulted in the etching of the surface of the seeds. Therefore, RF plasma can be used to pre-treat seeds to improve the yield of cereal crops.

It’s concluded that, the plasma treatment leads to increased water absorption (imbibition) of seeds. It was also important to verify the impact of increased water absorption on the germination process of seeds. So, the effect of plasma treatment on the germination of seeds will be investigated.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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