# INFLUENCE OF AIRCOLD PLASMA TREATMENT ON YIELD OF WHEAT

[1]MAHIN SABERI, [2]SEYEDALIMOHAMMAD MODARRES-SANAVY, [3]HAMID GHOMI

[1,2]DEPATMENT OF AGRONOMY, FACULTY OF AGRICULTURE, TARBIATMODARES UNIVERSITY, TEHRAN, IRAN
[3]LASER AND PLASMA RESEARCH INSTITUTE, SHAHID BEHESHTI UNIVERSITY, TEHRAN, IRAN.
E-mail: modaresa@modares.ac.ir

**Abstract** - The world's population will exceed 9 billion by 2050. To meet the future's need for agricultural products, the food production has to be doubled. Seed plasma treatment technology is recognized as a suitable way to improve plant yield.The objective of this paper is to demonstrate whether coldargon plasma can change the quality and quantity of wheat yield. These effects are determined by a randomized complete block design experiment with 3 replications in the cropping seasons 2015-17. Seeds were pre-treated with 50Wof cold plasma atfour-timelevels;60, 120, 180 and 240 seconds. Results showed that plasma treatments had positive effects on wheat characteristics, and treatment of 180s had the highest stimulatory effect.In both years, cold plasma increased 1000 grain weightat 180s,but decreased it at 240s compared with the control. The results indicated that 180s cold plasma treatment increased the spike number per $m^2$ andspike weight by as much as 34% and47%, respectively, compared with control.

**Keywords** - Radio frequency, sustainableagriculture, non-thermal plasma, plant physiology, climate change.

## I. INTRODUCTION

Wheat (Triticum spp.) is a major crop worldwide and is considered a strategic crop in several countries.Global wheat production in 2017 is estimated 739.9 million tons (FAO, 2017).One of the major challenges facing human society is the issue of food quantity and quality. Climate change and population growth,demand application of suitable approaches in order to increase agricultural production.Crop yield is extremely dependent of seed quality.Seed quality is an essential factor for crop production, especially in conditions the increasing riskiness due to climate change.Seed priming have various techniques for improving the performance of the growth, emergence, and yield of the crop(Taiz and Zeiger, 2006).

Recently, atmospheric-pressure plasmas have appearedas a matter of course competitive strategy to other methods of improvinggrain yield and disease resistance. Plasmaas a new technique for seed priming, is one of the four fundamental states of matter, and was first described by chemist Irving Langmuir in the 1929s (Goldeston and Rutherford, 1995). Langmuir (1929) was the first to name and describe plasma as ionized gas. The cold plasma contains different oxygen radicals, charged particles, ions and UV light, which hasstimulating effects on seeds (Langmuir and Tonks, 1929).

The cold plasma treatment is fast, healthy, economic method to enhance seed performance management, and improve plant production capacity(Dhayalet al., 2006). This treatment plays a critical role in physiological processes in plants, including the promotion of seed germination and seedling growth (Sera et al., 2008 and Li et al., 2014), activation of photosynthesis (Sera et al., 2010; Chen et al., 2012),and control of carbon and nitrogen metabolism rate (Henselovaet al.,2012 ; Zhou et al., 2012).Recently, non-thermal plasma is usedas a viable alternative to replace traditional methods such as seed treatment scarification, heat treatment, chemical treatment such as acid (Dhayalet al., 2006).Promising results were observed in increased germination of seeds of tomato (Zhouet al., 2011), safflower(Dhayalet al., 2006), lettuce(Wang et al., 2007a)and cucumber(Wang et al., 2007b).In soybean,germination and vigor indices significantly increased by14.66% and 63.33% respectively(Li et al., 2014). Kazunori et al. (2016) in a study conducted at Arabidiopsis thaliana showed a 56% increase in plasma caused the total weight of seeds and an increase of about 12% in the 100- grain weight and the seed number by 39%(Kazounoriet al., 2016).

## II. MATERIALS AND METHODS

2.1. Experimental location and general methodology
The research was carried out in the research field in Agricultural Research Station of TarbiatModares University, Tehran, Iran (35°41' N, 51°10' E and 1265 m above sea level) on a sandy-loam soil during October 2015 to July 2017.This area is a semi-arid area (according to the Köppen climate classification) characterized by warm and dry summers, long-term (30 years) mean annual rainfall of 232.6 mm and temperature of 17.6 °C, respectively. The monthly weather data recorded during the trial period in each year are given in Fig. 1.

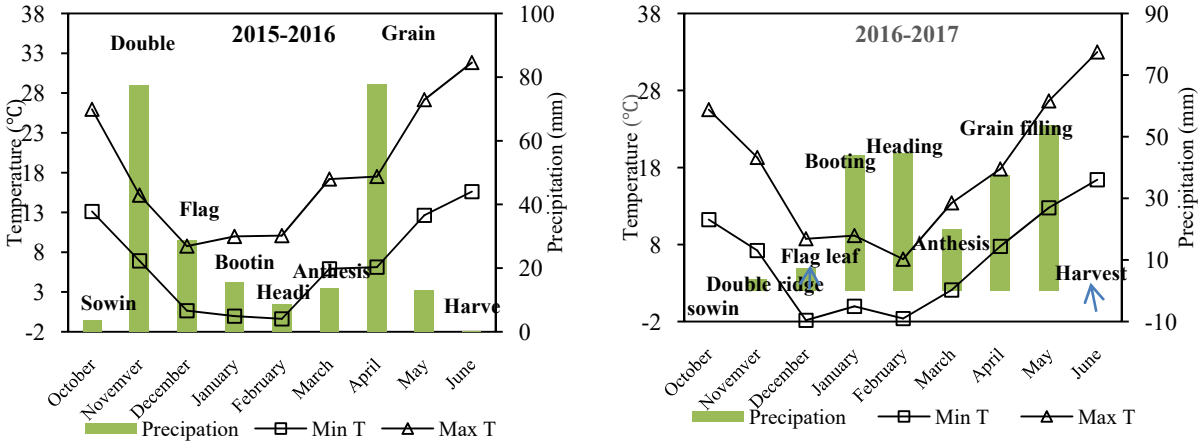


**Fig.1. Monthly maximum and minimum air temperatures (°C), and precipitation (mm) recorded during the growing season in 2015-16 and 2016-17.**

Before planting, 20 number of soil samples were taken at depths of 0–30 cm and tested for physical and chemical properties. Seeds cultivar (Pishgam variety) of wheat (Triticum aestivum L.) was obtained from Seed and Plant Improvement Institute (Karaj, Iran).

**Table 1. Soil Characteristics**

| Soil characteristic | pH | EC (ms) | Organic carbon OC% | N (%) | Available P (ppm) | Available K (ppm) | Available Zn (ppm) | Available Fe (ppm) | Available Ca (ppm) |
|---|---|---|---|---|---|---|---|---|---|
| | 7.83 | 0.61 | 0.896 | 0.130 | 22 | 277 | 1.51 | 8.13 | 1390 |

Note: EC, electrical conductivity; SP, saturation percentage

Seeds were treated by cold plasma from the argon with high voltage AC power supply with a voltage of 10 KV, 70 W at 13.56 MHz. RF plasma source power supply was the main structure (Fig. 2). Time treatments of cold plasma application on seeds were 0 (C, control), 60 (p1), 120 (p2), 180 (p3) and 240 (p4) seconds. To study the effect of plasma power on wheat seed, Plasma powers of 50, 80, and 100 W emission spectra at different conditions were registered with the use of a spectrometer (Ocean Optics HR2000 + ES) to determine plasma reactive species concentration.The spectrometer was able to measure the wavelength interval of 200 to 1100 nm (Fig. 3)

Area of field was divided into 15 experimental plots with 6 m long andfive rows. Between all the main plots, a 3 m alley was kept to eliminate the influence of lateral water movement. Plant to plant distance in each row was 12.5 cm. The seed of wheat landrace from central plateau of Iran was planted at140 kg $ha^{-1}$ on 9 October 2015 and 9 October 2016.Textures and elements of the soil were determined before planting (Table 1). The sufficientN, P and K were provided for wheat plants.The experiment was conducted in a randomized complete block design,four replications and two cropping seasons. In each plot, provided samples in the middle of the plot to avoid the border effects influencing on estimating of grain yield and yield component.

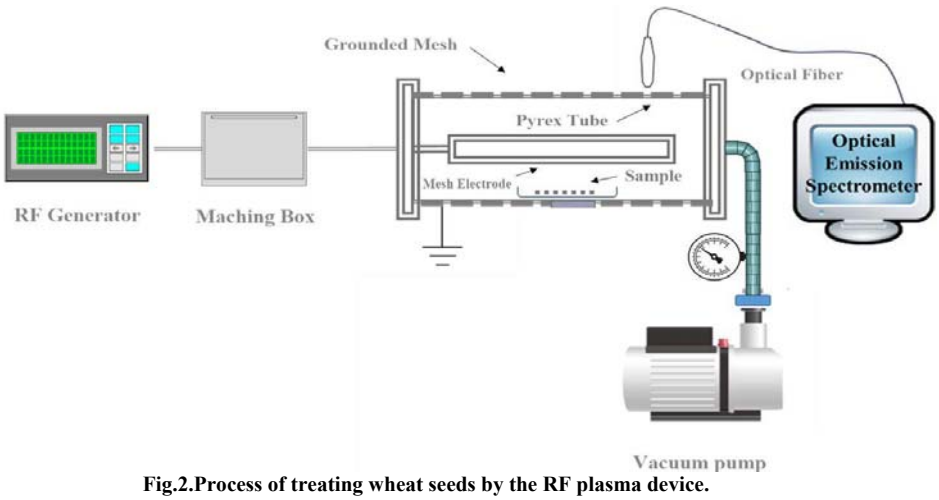


**Fig.2.Process of treating wheat seeds by the RF plasma device.**

### 2.3. Measurements

At the end of the growing season, plants from 1.5 $m^2$ area from each plot were taken to determine 1000 grain weight, spike weight and spike number per $m^2$.

### 2.4.Statistical analysis

Years were analyzed separately because Bartelett's test was significant for most traits measured. The effects of treatments were determined by analysis of variance (ANOVA) using SAS software(SAS, 2002). The assumptions of variance analysis were tested by ensuring that the residuals were random, homogenous, with a normal distribution about/above a mean of zero.LSD test at the 0.05 probability level was used to check significant differences between means.

## III. RESULTS

Spike number: The mean square values from analysis of variance table for SPAD chlorophyll contents showed that years (Y), treatment (T) and interaction between years and treatments (Y*T) have significant effect on SPAD value (Table 2).The analysis of variance indicated that the differences established between the years when the research was performed were highly significant, which is often the case in the study region (Tables 1).A general result of the plasma activation experiments was a chlorophyll contents improvement for the plasma treated seeds with some differences depending on the treatment time. A compilation of chlorophyll contentswheatplants as a function of seeding time for increasing periods of plasma treatment times is gathered in (Tables 2).Tables 2 shows that, in comparison with untreated seeds, those treated with RF plasmas for 120s and 180s experienced an improvement in chlorophyll contents(Tables 2).Tables 2 shows that, all plasma treatment improved in chlorophyll contents (Tables 2).In both years, the highest chlorophyll content was obtained in p3plasma treatment (Tables 2).

Grain per spike: There was a significant difference between years, treatments and T*Y for net photosynthesis rate (Table 1). One of the factors proposed in literature to explain the increase in yield usuallyfound for plasma treated seeds is an enhancement in photosynthesis rate. The effect of cold plasma on photosynthesis rate of wheat varied with different treatment time levels (Tables 1). In both years, the p3 treatment significantly increased the photosynthesis, compared with the control (Tables 2).In both years, the highest net photosynthesis rate was obtained in p3 plasma treatment, which indicated that the p3 plasma treatment could improve the grain yield of wheat plants and there was significant difference between p1, p2 and p4 plasma treatments and the control (Tables 2). 1000 Grain weight: There was a significant difference between years and treatments and interaction between them for wheat grain yield (Table 1). Figure 5a shows that, in comparison with untreated seeds, those treated with RF plasmas for 180 s experienced an improvement in grain yield (Tables 1).Similar to spike yield, a considerable decrease in grain yield was obtained for seeds treated for 240 s, indicating that, as found by others, an excess of RF plasma might be deleterious for grain yield, the surface damage induced on seeds that were RF treated for long periods of time (Sera et al., 2012; Slamaet al., 2013 and El-Aragi, 2016). Plasma treatment times of 180 s produced a grain yield success rate of 35.36% and 62.12% compared with control(Tables 2).In both years, the highest grain yield was observed in p3 treatment, which indicated that the p3 plasma treatment could improve the grain yield of wheat plants(Tables 2).

## IV. DISCUSSION

This study showed that the effect of plasma treatment on chlorophyll content (SPAD), chlorophyll a andchlorophyll b concentration and photosynthesis rate was significant in both years. Increasing the amount of chlorophyll in the leaves and a comparison with the control plasma treatment can be attributed to an increase in the leaf photosynthesis. Increased leaf photosynthesis increases the flow of materials in plant (Metwallyet al., 2003) and as the result grain filling and plant performance is increased (Hayat and Ahmad, 2007). Jiang et al. (2014) using cold helium plasma observed that the wheat leaf area increased by 13% and other researchers have focused on the effects of plasma enhanced chlorophyll (Sera et al., 2009; Henselovaet al., 2012).Due to plasma treatment the plant height is increased and as the result the plants were stronger for compete for more sunlight. Higher level of absorption of PAR (photosynthetically active radiation) causes higher stomatal conductance, leaf area and chlorophyll content (Sera et al., 2009).

Cold plasma had a positive effect on the grain yield, spike yield of wheat in both years. The 180 seconds (p3) cold plasma treatment produced the highest stimulatory effect among different treatments. Plasma incremental effects on the grain yield and spike increased the yield by 35.36%, and the seed weight by 19%. Seed treatment with plasma have different effects on seed morphological characteristics which depends on complex interactions between organic materials and living cells (Sera et al., 2008).Plasma changing seed coat structure, increasing the permeability of the seed coat and stimulating the seed germination in plants such as Chenopodium album(Sera et al., 2008), Oryza sativa(Chen et al., 2012), Triticum aestivum(Sera et al., 2010), and Solanum melongena(Zhou et al., 2012).The cold plasma exposes the seeds to oxygen radicals and ions,

thus attacks and erodes the seed surface(Stoffelset al., 2008).

Li et al.(2014) indicated that changes occurring in the seed coat, enhance hydrophilic ability of the seeds, improving water uptake by the seed (Fig, 4), thus increasing the weight of transferred reserves. Reduction of seed grain reserves is the most important factor determining the efficiency and initial growth and development of the seedling(Soltaniet al., 2006; Li et al., 2015). Kocet al. (2003) observed that plasma improved relationship between cells and enzymes, such as alpha-amylase and protease. These enzymes play important roles in germination process (Del Blanco et al., 2000 and Dobryninet al., 2009).It was also concluded that the plasma treatment may accelerate the decomposition of carbohydrates and soluble proteins (Selcuket al., 2008; Dobryninet al., 2009;Jiafenget al., 2014). Carbohydrates are the main product of photosynthesis playing a significant role in plant metabolism. Many studies show that soluble carbohydrates are closely related to photosynthesis and yield (Tian et al., 2010). Numerous studies have found that cold plasma significantly increased seed germination and yield. Seraet al. (2008; 2010) found that plasma treatment increased the seed yield of Chenopodium album, wheat and oat. Previous research that used cold helium plasma increased yield by 5.89% (Jiang et al., 2014).

Interestingly it wasfound that the plasma treatment time of 240s reduced grain yield compared with the control. Excessive application of plasma flow causes production of extra reactive oxygen species (ROS). ROS along with normal metabolic processes take place in all aerobic organisms(Alscheret al., 2002). Filatovalet al.(2013) found that longer time of plasma treatment of spring wheat reduced the germination down to 70 % which was due to the damage of seeds inflicted by plasma bombardment.

The yield and yield components were higher in 2016 than in 2017, which is attributable to the weather conditions in two years. In 2016, during the grain filling, there was 40 mm increase in rainfall and 2°C decrease in temperature (Fig. 1). This causes longer growth period which in turn increases the chlorophyll content and net photosynthesis rate in 2016 compared to 2017 that was concordant with the results of Mokhtassi-Bidgoliet al. (2013).

## CONCLUSION

The focus of this paper was on the increase of quality and quantity of wheat yield following treatments of wheat seeds by argon cold plasma. The results of two years of study showed significant yield increase was achieved following treatment after 180s exposure of seeds with cold plasma. 1000 Grain weight was increased by 35.36respectively.

## REFERENCES


[1] Alscher RG, Erturk N, and Heath LS, 2002. Role of superoxide dismutase (sod) in controlling oxidative stress in plant.J. Exp. Bot. 153:1331-1341.

[2] Chen HH, Chen YK, and Chang HC, 2012. Evaluation of physicochemical properties of plasma treated brown rice. Food Chem. 135: 74–79.

[3] Dhayal M, Lee SY, and Park SU, 2006. Using low-pressure plasma for CarthamustinctoriumL. seed surface modification Vacuum. 80:499–506.

[4] Del Blanco IA, Rajaram S, Kronstad WE, and Reynolds MP, 2000. Physiological performance of synthetic hexaploid wheat–derived populations. Crop Sci. 40: 1257–1263.

[5] Dobrynin D, Fridman G, Friedman G, and Fridman A, 2009. Physical and biological mechanisms of direct plasma interaction with living tissue. New J. Phys.11:2–26.

[6] El-Aragi GM, 2016. The effect of plasma treatment on growth and yield of berseem (Egyptian clover) crop. JOPA. 4: 18–22.

[7] FAO, 2017.World Food Situation, FAO, Rome.

[8] FilatovaI, Azharonok V, Kadyrov M, Beljavsky V, Gvozdov A, Shik A, and Antonuk A,2013. Plasma seeds treatment as a promising technique for seed germination improvement. 31st ICPIG, July 14-19, Granada, Spain,

[9] Goldston RJ, and Rutherford PH, 1995. Introduction to Plasma Physics Taylor and Francis.

[10] Hayat S, and Ahmad A, 2007. Salicylic acid: a plant hormone,Springer US,Chapter. 3: 69- 89.

[11] Henselová M, Slováková L, Martinka M, and Zahoranová A, 2012. Growth, anatomy and enzyme activity changes in maize roots induced by treatment of seeds with low-temperature plasma.Biologia. 67:490–497.

[12] Jiang J F, He X, Li L, Li JG, Shao HL, Xu QL, Ye HR, and Dong, YH, 2014. Effect of cold plasma treatment on seed germination and growth of wheat. Plasma Sci. Technol. 16: 54–58.

[13] Jiafeng J,Xin H,Ling Li, Jiangang Li, Hanliang S,Qilai Xu, Renhong Ye, and Yuanhua D,2014. Effect of Cold Plasma Treatment on Seed Germination and Growth of Wheat. Plasma Sci. Tech. 16: 54-58.

[14] Kazunori K, Sarinont T, Takaaki A, Hyunwoong S, Naho I, and Nobuya H,2016.Simple method of improving harvest by nonthermal air plasma irradiation of seeds of Arabidopsis thaliana (L.). Appl. Phys. Express. 9: 016201.

[15] Koc N, Barutcular C, and Genc I,2003. Photosynthesis and productivity of old and modern durum wheat in a Mediterranean environment. Crop Sci. 43: 2089–2098.

[16] Krotz L, Cicerci E, and Giazzi G, 2008. Protein Determination in Cereals and Seeds.J. Food Qual. 15(4): 37–39.

[17] Langmuir I,and Tonks L, 1929. Ion oscillations in a warm plasma. Phys. Rev. 33: 195–210.

[18] Ling L, Jiafeng J, Jiangang Li, Minchong S, Xin He, Hanliang S, and Yuanhua D, 2014. The effects of cold plasma on seed germination and seedling growth of soybean. Sci. Rep.4:5859–5865.

[19] Ling L, Jiangang L, Chunlei Z, and Yuanhua D,2015. Cold plasma treatment enhances oilseed rape seed germination under drought stress.Sci. Rep. 5:13033.

[20] Metwally A, Finkemeier I, Georgi M, and Dietz KJ, 2003. Salicylic acid alleviates the cadmium toxicity in barley seedlings.J. Plant Physiol. 132: 272-281.

[21] Mc Leary BV, Solah V, and Gibson TS, 1994. Quantitative measurement of total starch in cereal flours and products. J. Cereal Sci. 20: 51-58.

[22] Mokhtassi-Bidgoli A, Navarrete L, AghaAlikhani M, and Gonzalez-Andujar JL,2013. Agronomic performance, seed quality and nitrogen uptake of Descurainiasophia in response to different nitrogen rates and water regimes. Ind. Crops Prod. 44, 583–592.

[23] SAS Institute Inc, 2004. SAS/STAT user's guide. Version 9.1. SAS Institute Inc. Cary: North Carolina, http:www.sas.com.

[24] Sera B, Stranak V, Serý M, Tichy M, and Spatenka P,2008.

Germination of Chenopodium Album in esponse to microwave plasma treatment. Plasma Sci. Technol.10:506–511.
[25] Sera B, Spatenka P, Sery M, Vrchotova N, and Hruskova I, 2010. Influence of plasma treatment on wheat and oat germination and early growth. IEEE Trans Plasma Sci. 38: 2963–2968.
[26] Sera B, Sery M, Stranak V, Spatenka P, and Tichy M, 2009. Does cold plasma affect breaking dormancy and seed germination? A study on seeds of lambs quarters (Chenopodium album agg.), Plasma Sci. Technol. 11:749–754.
[27] Selcuk M, Oksuz L, and Basaran P, 2008. Decontamination of grains and legumes infected with Aspergillus spp. and Penicillumspp. by cold plasma treatment. Bioresour Technol. 99.
[28] Stoffels E, Sakiyama Y, and Graves DB, 2008. Cold atmospheric plasma: charged species and their interactions with cells and tissues.IEEE T. Plasma Sci.36: 1441–1451.
[29] Stolarik T, Henselová M, Martinka M, Novák O, Zahoranová A, and Černák M,2015.Effect of Low-Temperature Plasma on the Structure of Seeds, Growth and Metabolism of Endogenous Phytohormones in Pea (Pisum sativum L.).Plasma Chem. Plasma Proc.35: 659-676.
[30] Soltani A, Gholipoor M, and Zeinali E, 2006. Seed reserve utilization and seedling growth of wheat as affected by drought and salinity. Environ. Exp. Bot.55:195–200.
[31] Sláma J, Kříha V, Julák J, and Fantova V, 2013. Comparison of dielectric barrier discharge modes fungicidal effect on candida albicans growth. BAHT. 83: 237–239.
[32] Taiz L, and Zeiger E,2006. Plant Physiol. 4th ed. 764 pp.
[33] Tian BQ, Xie BJ, Shi J, Wu J, Cai Y, Xu TM, Xue S, and Deng QC, 2010. Physicochemical changes of oat seeds during germination, Food Chem. 119: 1195–1200.
[34] Tong J, Rui He,Xiaoli Z, Ruoting Z, Weiwen C, and Size Y, 2014. Effects of atmospheric pressure air plasma pretreatment on the seed germination and early growth of Andrographis paniculata. Plasma Sci. Technol. 16: 260–266.
[35] Wang M, Chen QY, and Chen GL, 2007a. Acta AgriculturaeBoreali-Sinica, 22: 108.
[36] Wang M, Yang SZ, and Chen QY, 2007b. Transactions of the Chinese Society of Agricultural Engineering. 23: 195.
[37] Wu ZH, Chi LH, Bian SF, and Xu KZ, 2007. Effects of plasma treatment on maize seeding resistance. J Maize Sci.15:111–113.
[38] Yin MQ, Huang MJ, Ma BZ, and Ma TC,2005. Stimulating effects of seed treatment by magnetized plasma on tomato growth and yield.Plasma Sci. Techno.7: 3143–3147.
[39] Zhou ZW, Huang YF, Yang SZ, and Xiong DY, 2012.Progress in electromagnetics research symposium proceedings. Kuala Lumpur, Malaysia2012, 1577.

**Table 1. Analysis of variance of characteristics in wheat under levels of plasma treatment**

| | | Mean square | | |
|---|---|---|---|---|
| Source | df | Spike number ($m^{-2}$) | Grain per spike | 1000 grain weight |
| Y | 1 | 4324175.53** | 260736.34** | 235.20** |
| R(Y) | 4 | 280543.71 | 13230.92 | 8.06 |
| T | 4 | 677069.91** | 58468.14** | 20.21 |
| T*Y | 4 | 125287.86 | 31485.96** | 10.28 |
| Error | 16 | 78301.23 | 5038.82 | 9.52 |
| Cv(%) | | 14.38 | 12.08 | 9.66 |

Notes: * and ** Significant at 5% and 1% probability levels, respectively. Y, year; R(Y), replication year; T, treatments; T*Y, interaction between treatments and years; d.f, degree of freedom; CV, coefficient of variation.

**Table 2.Mean comparison of effect of cold plasma on characteristics of wheat in the field**

| Treatments | Year | Spike number ($m^{-2}$) | Grain per spike | 1000 grain weight (g) |
|---|---|---|---|---|
| Control | 2016 | 1980.0b | 62.33b | 32.00b |
| | 2017 | 1285.83c | 46.73b | 27.00a |
| 60s | 2016 | 2773.3a | 76.80ab | 34.00ab |
| | 2017 | 1857.87a | 51.87ab | 28.33a |
| 120s | 2016 | 2403.3ab | 72.53ab | 35.00ab |
| | 2017 | 1681.20ab | 52.47ab | 29.33a |
| 180s | 2016 | 2740.3a | 84.0a | 39.33a |
| | 2017 | 1618.93b | 59.47a | 31.00a |
| 240s | 2016 | 1726.7b | 45.13c | 33.33ab |
| | 2017 | 1383.27c | 36.00c | 30.00a |

Note: Means in each column followed by similar letter(s) are not significantly different at 5% probability level using Duncan Multiple Rang Test.

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