# Modeling of Water Absorption of Cold Plasma Treated Six Chickpea Cultivars (*Cicer arietinum*) Using Peleg's Equation


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## 1. Abstract


Application of the Peleg model was investigated for predicting the water absorption by six chickpea cultivars during soaking at ambient temperature with cold plasma treatment (40, 50 and 60 V) each with an exposure time 10, 15, 20 minutes and without plasma treatment in 1% sodium bicarbonate solution. Cold plasma treatment was found to affect the rate of water absorption of Chickpea cultivars. There was no effect of cold plasma treatment on water absorption capacity of Chickpea cultivars. $K_1$ (Peleg rate constant) decreased from $22.7*10^{-3}$ to $10*10^{-3}$ (h % $^{-1}$) for Kripa, $1.8*10^{-3}$ to $4.3*10^{-3}$ (h % $^{-1}$) for Virat, from $30*10^{-3}$ to $12.5*10^{-3}$ (h % $^{-1}$) for Visahl, $29.3*10^{-3}$ to $12.7*10^{-3}$ (h % $^{-1}$) for Vijay, from $29.4*10^{-3}$ to $4.9*10^{-3}$ (h % $^{-1}$) for Digvijay, and $32.4*10^{-3}$ to $10.8*10^{-3}$ (h % $^{-1}$) for Rajas with increase in voltage and exposure time of plasma treatment. $K_2$ (Peleg capacity constant) increased from $9.2*10^{-3}$ to $11.4*10^{-3}$ (% $^{-1}$) for Kripa, from $10.2*10^{-3}$ to $11.8*10^{-3}$ (% $^{-1}$) for Virat, $9.3*10^{-3}$ to $11.3*10^{-3}$ (% $^{-1}$) for Vishal, from $10.8*10^{-3}$ to $11.3*10^{-3}$ (% $^{-1}$) for Vijay, $10.6*10^{-3}$ to $12*10^{-3}$ (% $^{-1}$) for Digvijay and from $10.4*10^{-3}$ to $11.7*10^{-3}$ (% $^{-1}$) for Rajas with increase in voltage and exposure time of plasma treatment. Peleg model was successfully fitted to correlate water absorption of Chickpea cultivars. The model fit resulted in $R^2 \geq 0.9993$ for Virat, $R^2 \geq 0.9963$ for Rajas, $R^2 \geq 0.9955$ for Digvijay, $R^2 \geq 0.9950$ for Vijay, $R^2 \geq 0.9941$ for Kripa and $R^2 \geq 0.9913$ for Vishal $R^2 \geq 0.988$ with soaking time and cold plasma treatment.



***Keywords:*** **Peleg model; Water absorption; Cold Plasma;**


## 2. Materials and methods

***2.1 Materials***

The six chickpea cultivars (*Cicer arietinum*) samples were procured from the Pulses Improvement Project, MPKV, Rahuri. The names of cultivars are Kripa, Virat [Kabuli type] Vishal, Vijay, Digvijay, Rajas [Desi type]. Initial moisture contents of the samples were 8.4, 8.2, 10, 10.10, 9.3 and 9.1 % dry basis for all the chickpea cultivars respectively. The seeds were sieved to remove foreign materials and damaged seeds.

***2.2 Cold Plasma Device***

The cold plasma device used was a low pressure bell-jar type radio frequency plasma reactor having frequency 13.56MHz. The electrode distance was maintained at 2cm during all the plasma treatments. The electrodes used were made of aluminum.

***2.3 Water absorption determination during soaking***

The soaking of six cultivars of chickpea was performed at ambient temperatures with 40, 50 and 60 V cold plasma treatment each having an exposure time of 10, 15 and 20 minutes and without cold plasma treatment (control) in 1% sodium bicarbonate solution. Experiments were conducted in 250 ml beakers containing 200 ml 1% sodium bicarbonate solution.

For each experiment, 8 gram grains were randomly selected, weighed and placed in a beaker. During soaking, grains were removed at interval of 1hr., superficially dried with a tissue paper and weighed using an electronic balance and returned to the beaker.

Experiments were terminated when kernel moisture content attained an equilibrium value, i.e., when the incremental change in sample mass was less than 0.001 g when measured after 1 h of soaking. Experiments were conducted in triplicate.

Moisture content of the samples (M) at each time step was calculated based on the increase in sample mass at corresponding times.

***2.4 Modeling of the legume seeds water absorption as a function of time***

Peleg (1988) proposed a two-parameter sorption equation and tested its prediction accuracy during water vapor adsorption of milk powder and whole rice, and soaking of whole rice. This equation has since been known as the Peleg model, which is as

$$M_t = M_0 \pm \frac{t}{K_1 + K_2 t} \qquad (1)$$

Where $M_t$ is moisture content at time t (% d.b.), Mo is initial moisture content (% d.b.), t is time (h), $K_1$ and $K_2$ are the Peleg rate (h%$^{-1}$) and Peleg capacity constant (%$^{-1}$) respectively. In equation (1), **'±' becomes '+' if the process is absorption and '-' if the process is drying or desorption.**

The rate of sorption (*R*) can be obtained from first derivative of the Peleg equation

$$R = \frac{dM}{dt} = \pm \frac{K_1}{(K_1 + K_2 t)^2} \qquad (2)$$

The Peleg rate constant $K_1$ relates to sorption rate at the starting ($R_o$), *i.e., R* at *t* = *t*$_o$

$$R_0 = \left.\frac{dM}{dt}\right|_{t_0} = \pm \frac{1}{K_1} \qquad (3)$$

The Peleg capacity constant $K_2$ relates to maximum (or minimum) attainable moisture content. Ast $\rightarrow \infty$, Eq. (4) gives the relation between equilibrium moisture content (**$M_e$**) and **$K_2$**

$$M\big|_{t_\infty} = M_e = M_0 \pm \frac{1}{K_2} \qquad (4)$$

| Abbreviations | |
|---|---|
| $K_1$ | Peleg rate constant, h % d.b.$^{-1}$ |
| $K_2$ | Peleg capacity constant, % d.b.$^{-1}$ |
| $M_t$ | Moisture content at time t, % d. b. |
| $M_0$ | Initial moisture content, % d.b. |
| $M_e$ | Equilibrium moisture content, % d. b. |
| $M_{exp}$ | Experimental moisture content, % d.b. |
| $M_{pre}$ | Predicted moisture content, % d. b. |
| $R_2$ | Co-efficient of determination. |
| RMSE | Root mean square error |
| V | Voltage , volts |
| T | Time, hours |
| N | Number of observations |
| d. b. | Dry basis |

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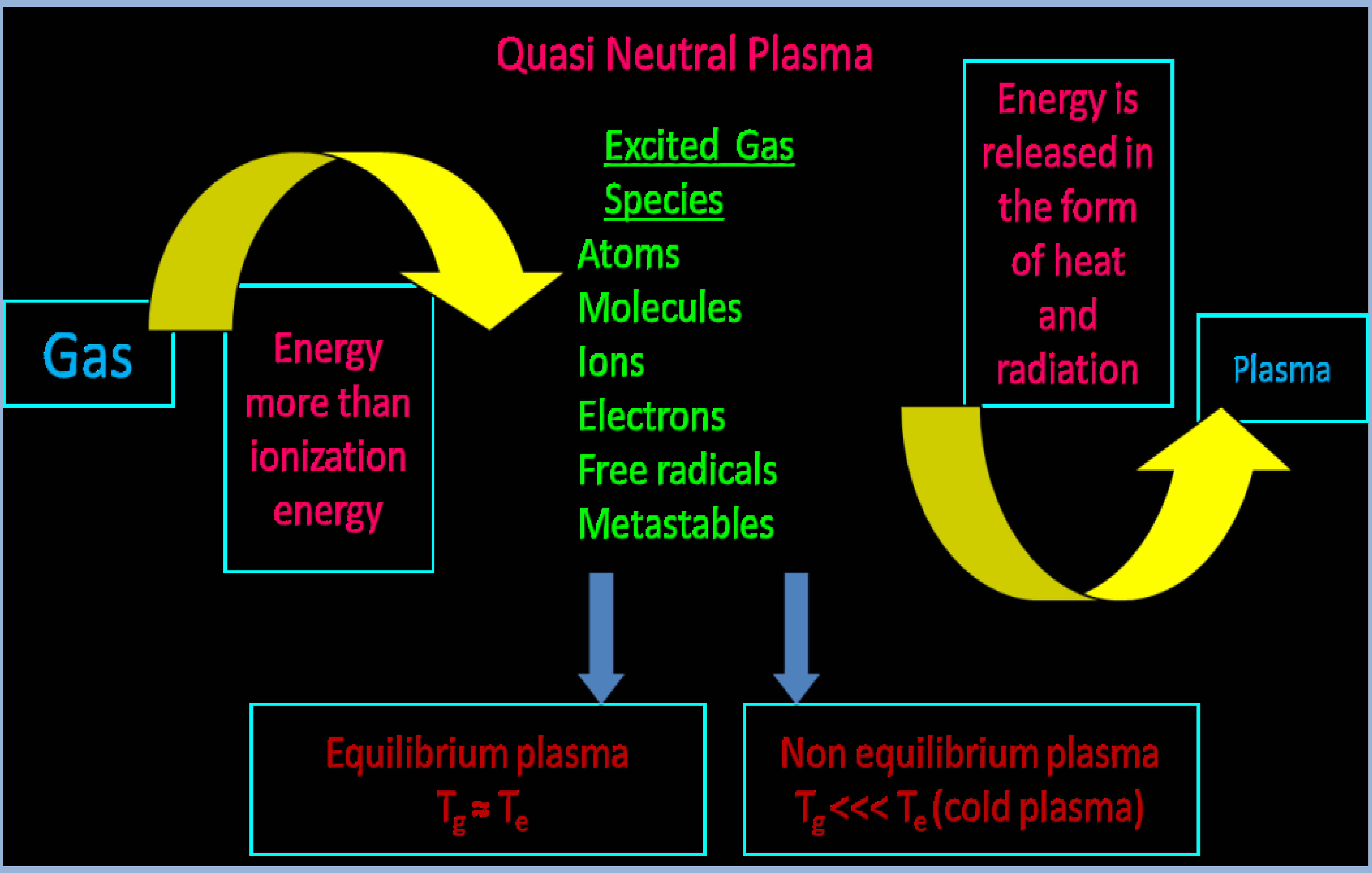
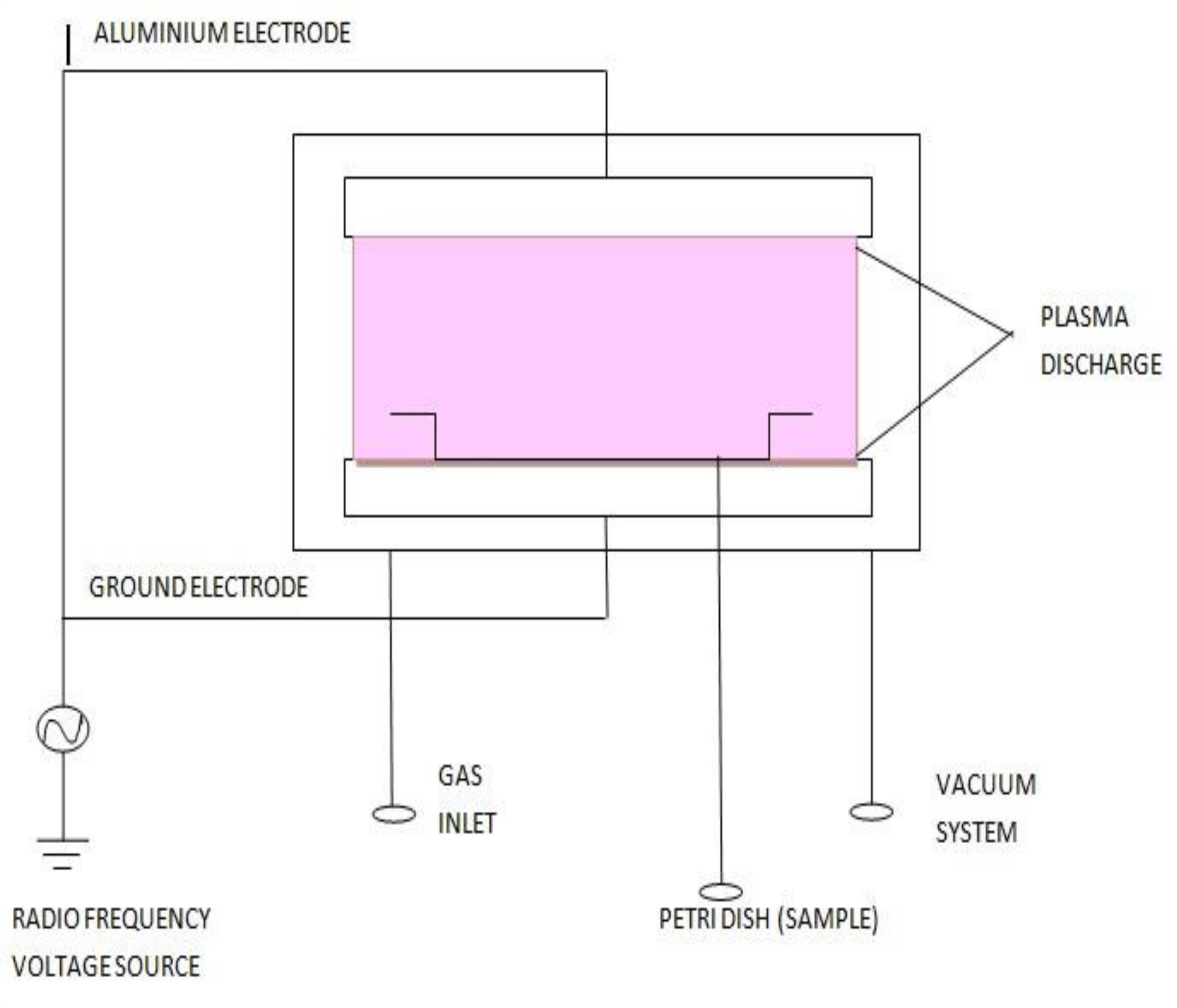
## Technology of Plasma Production and Composition




## Schematic Experimental Setup for Low Pressure Plasma System




## Plasma Apparatus in Working Condition

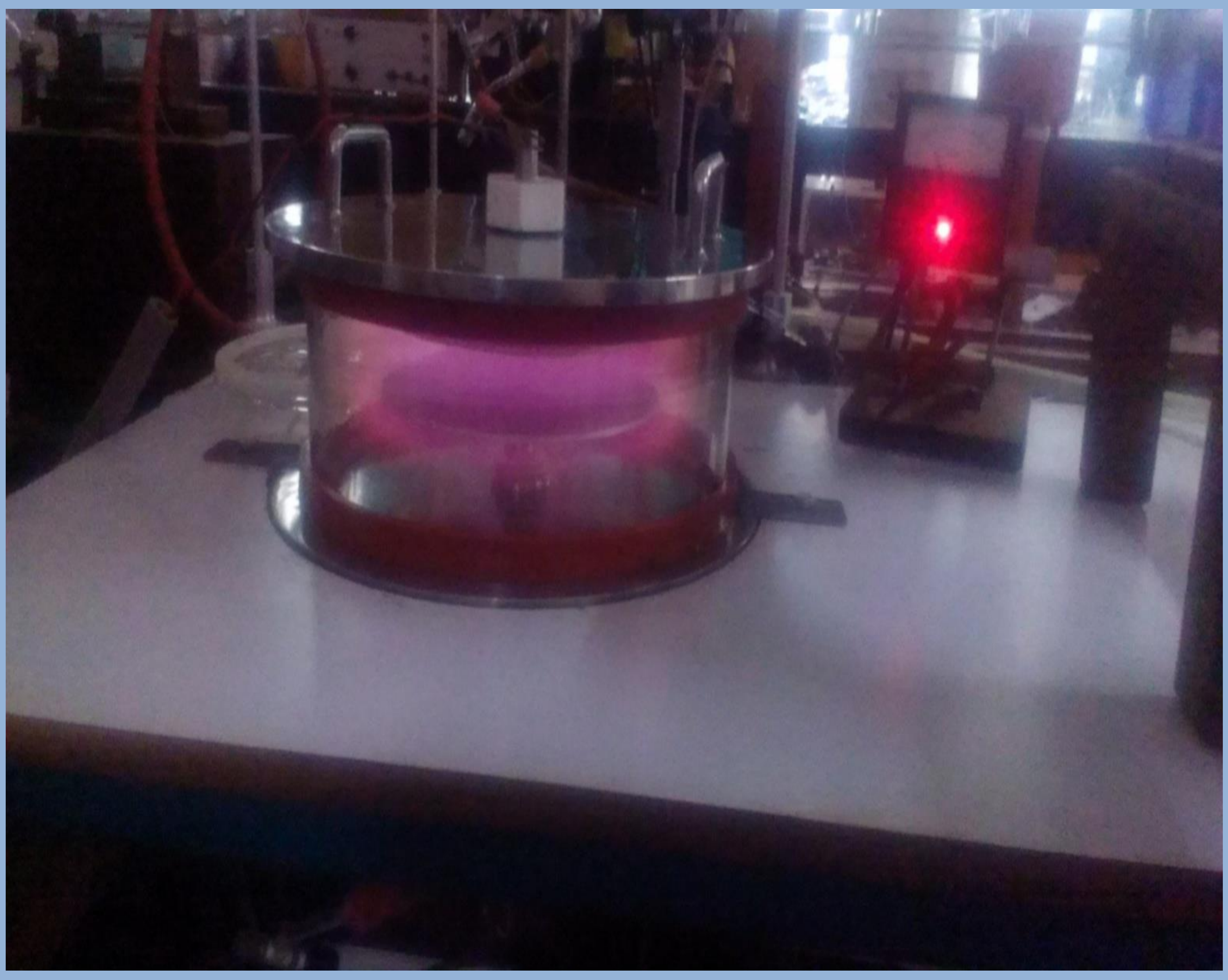


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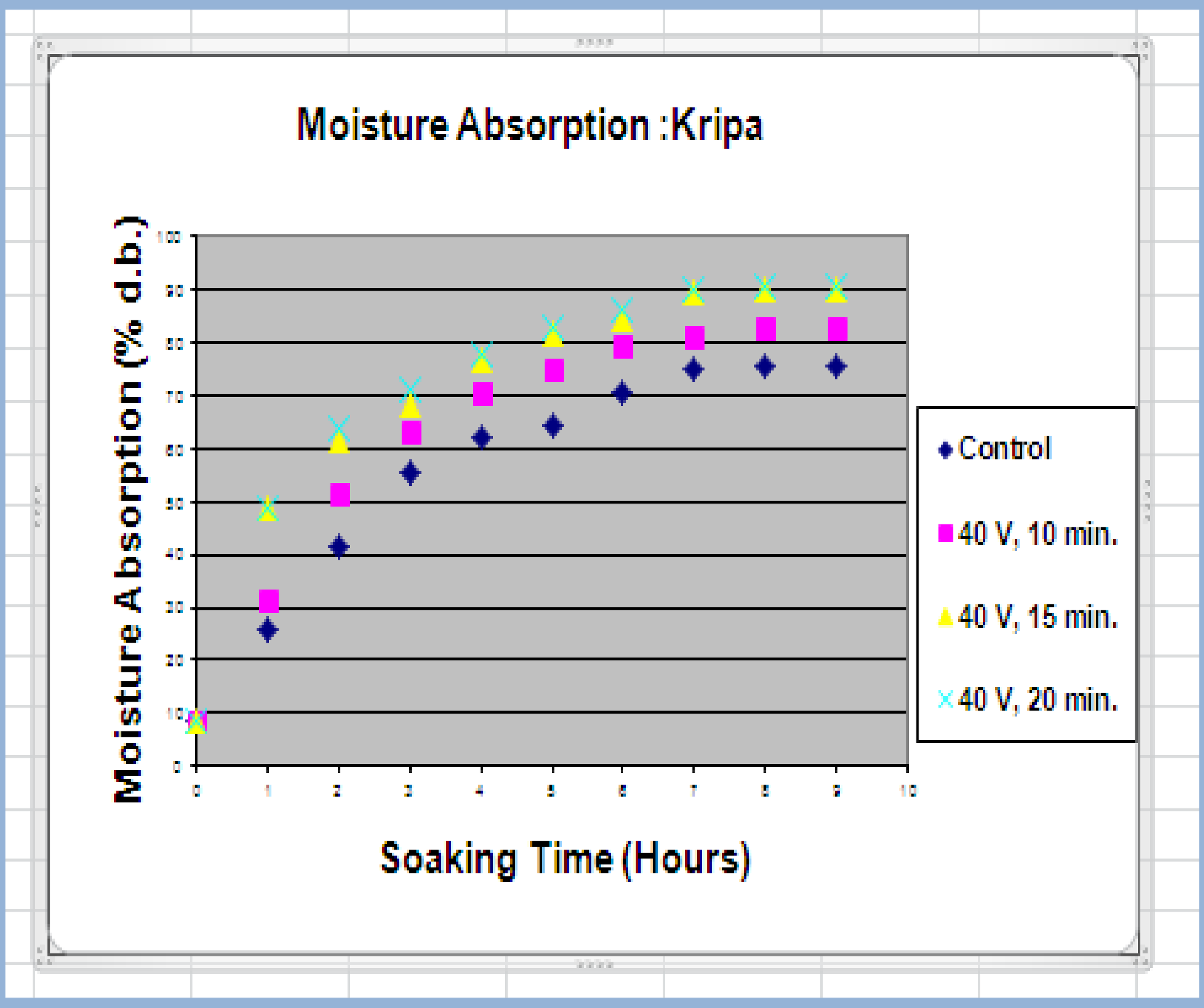
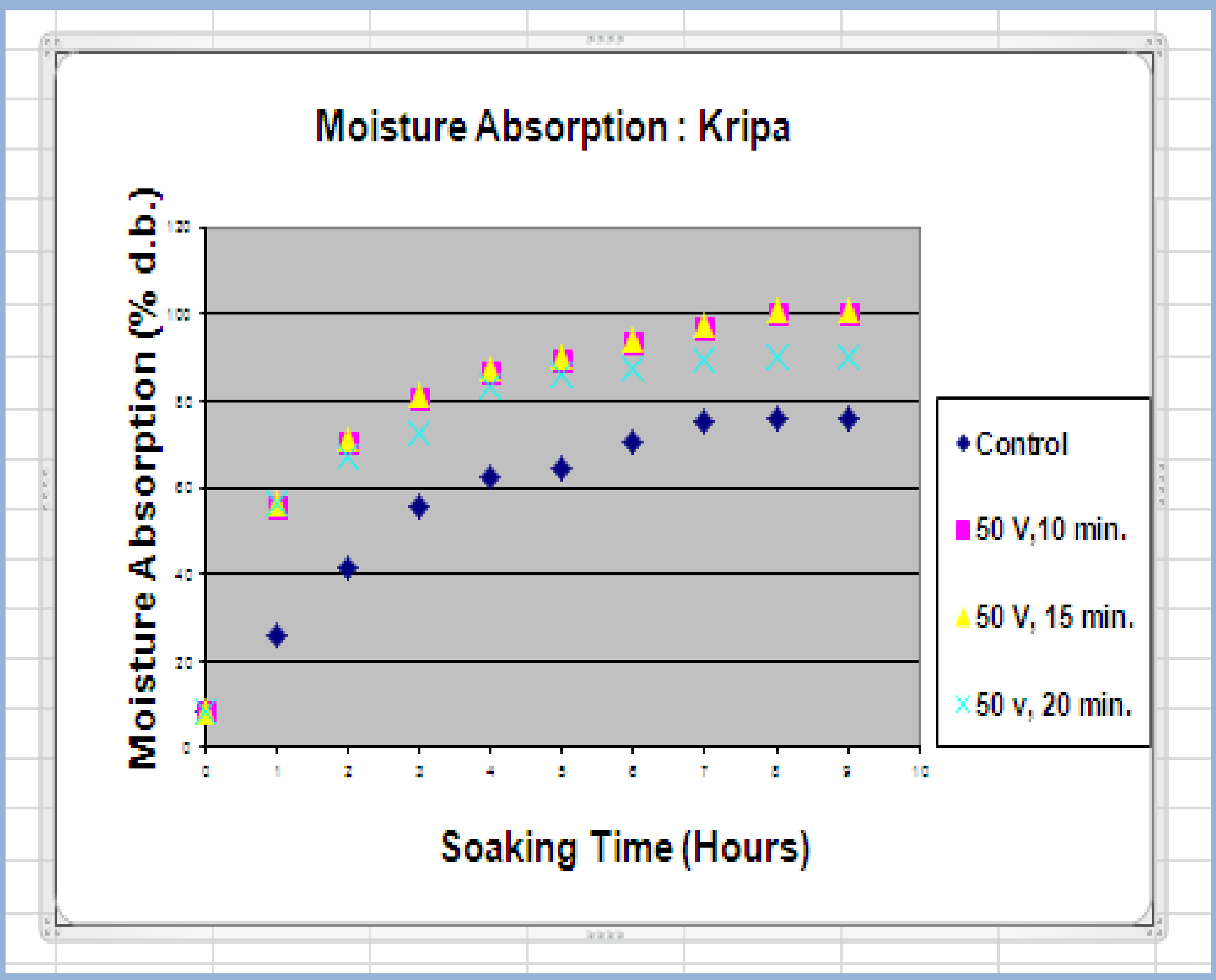
**Figure 1.** Variation of moisture content of the cold plasma treated and untreated chickpea cultivar (Kripa) during soaking in 1% sodium bicarbonate solution (40, 50, 60 V treatment for10, 15, 20 minutes)



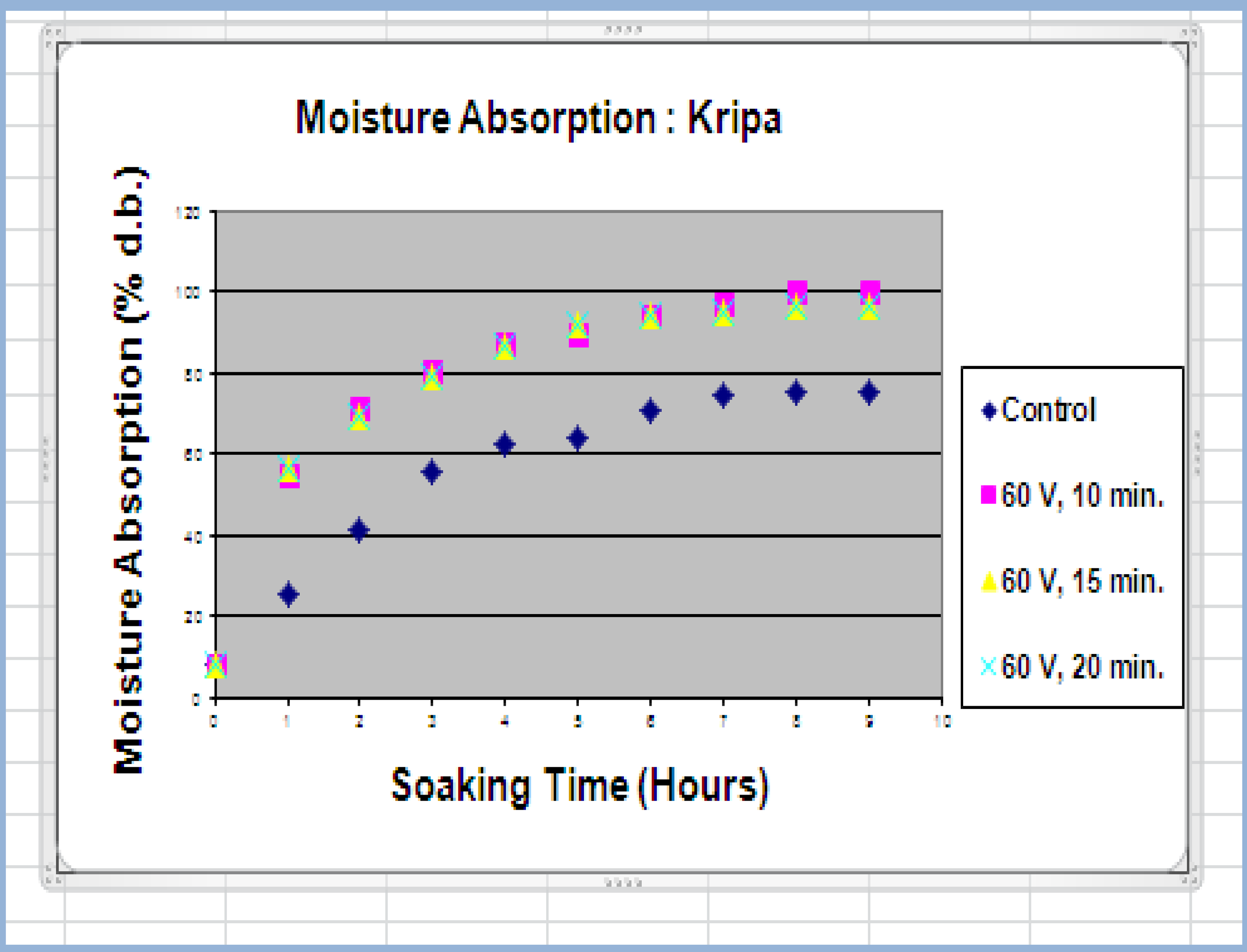
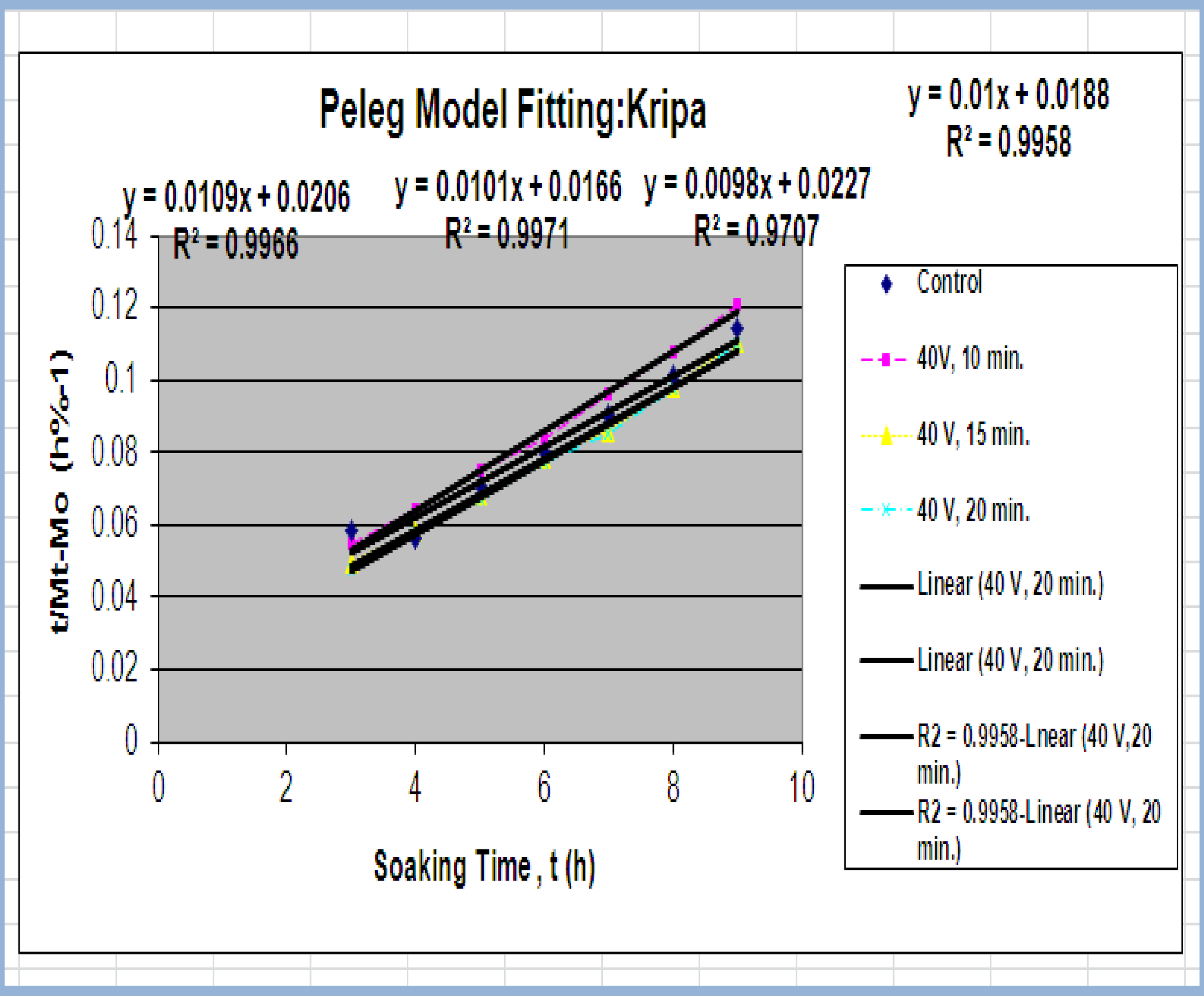
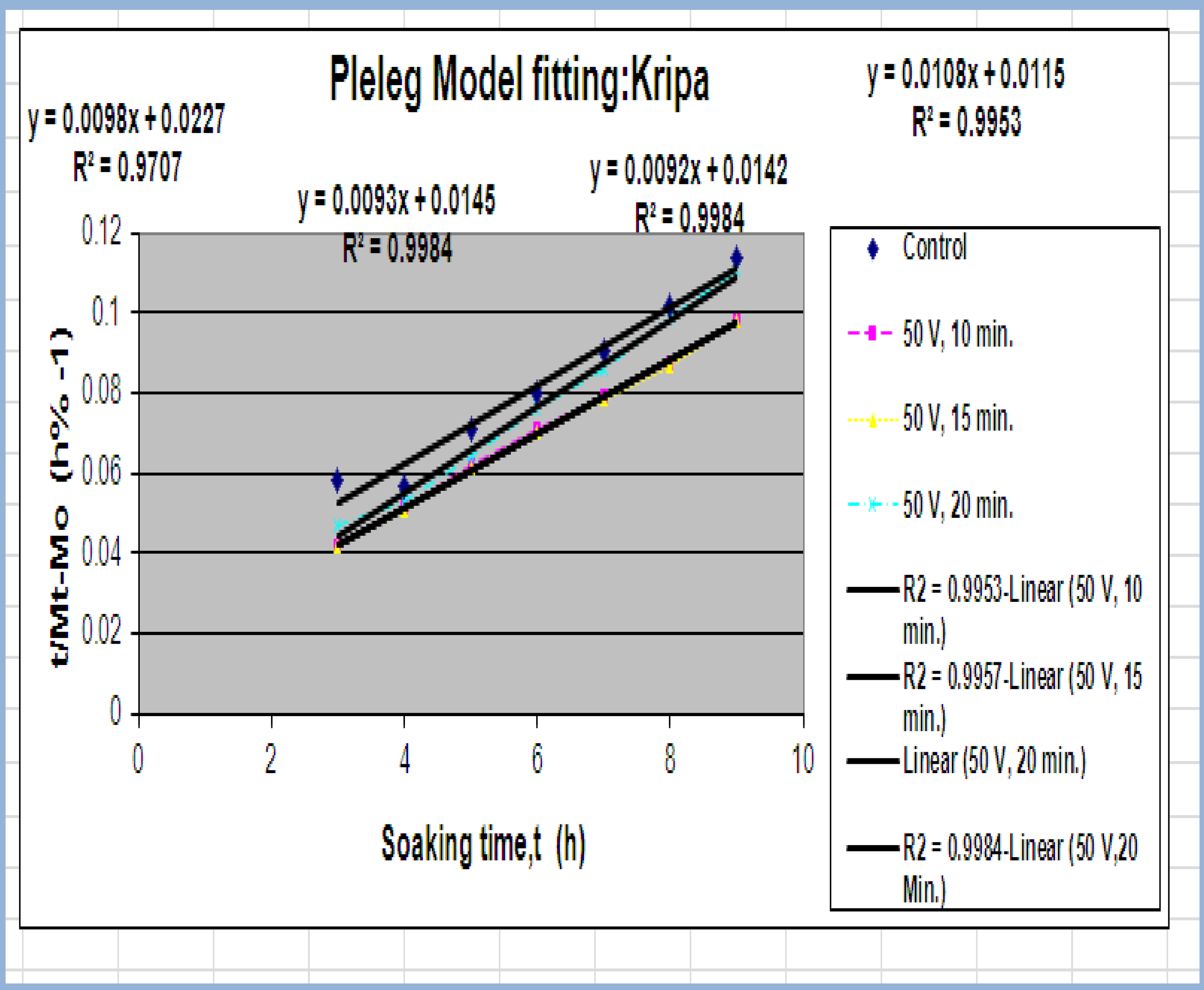




**Figure 2.** Fitting of the Peleg model to water absorption data of untreated and cold plasma treated chickpea cultivar (Kripa) during soaking in 1% sodium bicarbonate solution. (40, 50, 60 V treatment for10, 15, 20 minutes)



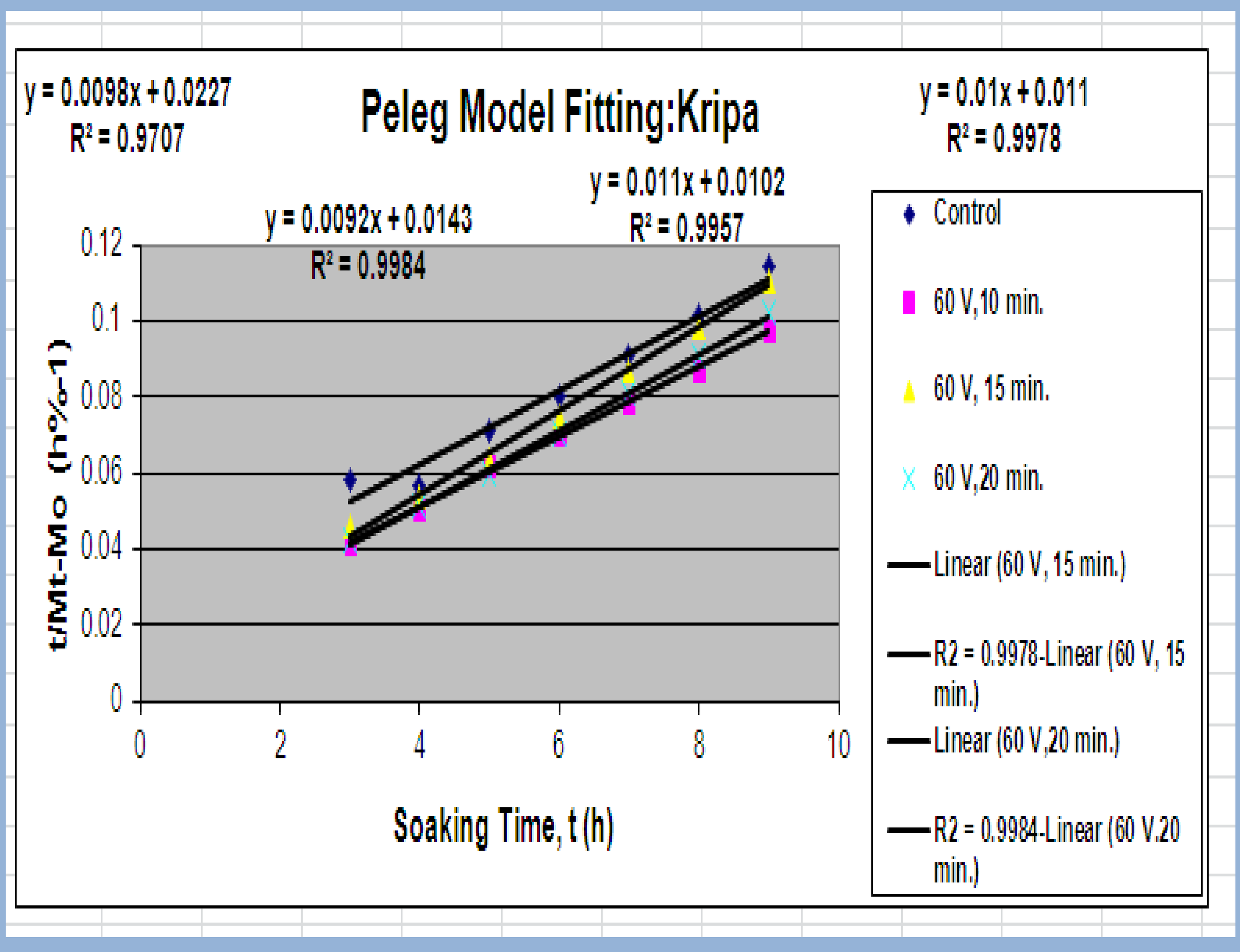



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**Table 1.** Average Peleg constants and goodness of fit of Peleg model for water absorption of the untreated and cold plasma treated chickpea Cultivar (Kripa) in 1% sodium bicarbonate solution

| Plasma Treatment | | $K_1 * 10^{-3}$ ($h\%^{-1}$) | $K_2 * 10^{-3}$ ($\%^{1}$) | $R^2$ | RMSE(%)[a] |
|---|---|---|---|---|---|
| Voltage (V) | Exposure Time (min.) | | | | |
| *Kripa* | | | | | |
| Control | - | 22.70 | 9.80 | 0.9707 | 0.11 |
| 40 | 10 | 20.60 | 10.90 | 0.9966 | 0.063 |
| | 15 | 18.80 | 10.00 | 0.9958 | 0.036 |
| | 20 | 16.60 | 10.10 | 0.9971 | 0.027 |
| 50 | 10 | 14.50 | 9.30 | 0.9984 | 0.028 |
| | 15 | 14.20 | 11.40 | 0.9957 | 0.35 |
| | 20 | 11.50 | 10.80 | 0.9953 | 0.064 |
| 60 | 10 | 14.30 | 9.20 | 0.9984 | 0.026 |
| | 15 | 10.20 | 11.00 | 0.9957 | 0.063 |
| | 20 | 10.00 | 11.oo | 0.9978 | 0.14 |

[a] Root mean square error, %,

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## 3. Results and Discussions

***3.1 Water absorption characteristics of the legume seeds during soaking***

The mean moisture content of the soaked chickpea cultivars in 1% sodium bicarbonate at ambient temperature, both untreated and treated with cold plasma are illustrated in Figure 1.

Rate of increase in moisture content for all the six chickpea cultivars was higher during the early stages of soaking but decreased gradually in the late soaking periods.

At each treatment voltage and exposure time, Virat cultivar had a relatively higher moisture gain (water absorptivity) than all the chickpea cultivars used in this study. This is relatively followed by Digvijay, Kripa, Rajas, Vijay and Vishal respectively.

***3.2 Modeling of the legume seeds water absorption as a function of time***

Data through $t_0$ and $t_\infty$ were used to determine the goodness of fit of the Peleg model. The model fit resulted in $R^2 \geq 0.9993$ for Virat, $R^2 \geq 0.9963$ for Rajas , $R^2 \geq 0.9955$ for Digvijay, $R^2 \geq 0.9950$ for Vijay, $R^2 \geq 0.9941$ for Kripa and $R^2 \geq 0.9913$ for Vishal at all conditions and a typical fit is presented in Figure 2. Table 1 provides $R^2$ and RMSE % values obtained from fit of Eq. (1). The water uptake fitted by Peleg's non-linear equation with co-efficient untreated seeds and seeds treated with cold plasma.

The Peleg model was successfully fitted to correlate water absorption of six cultivars of chickpea viz. Kripa ($R^2$=0.9707-0.9984 and *RMSE* (%) = 0.026-0.35), Virat ($R^2$=0.9983-0.9999 and *RMSE* (%) =0.012-0.036) , Vishal ($R^2$=0.9807-0.9972 and *RMSE* (%) =0.033-0.27), Vijay ($R^2$=0.9912-0.9972 and *RMSE* (%) =0.039-0.33), Digvijay ($R^2$=0.9921-0.9995 and *RMSE* (%) =0.016-0.96) and Rajas ($R^2$=0.9853-0.9990 and *RMSE* (%) =0.025-0.11) with soaking time and cold plasma treatment.

***3.2.1 Assessment of Peleg rate constant $K_1$***

$K_1$ is a constant related to mass transfer rate, e.g., the lower the $K_1$, the higher the initial water absorption rate. $K_1$ values of the Peleg model of all the plasma treated samples were lower compared to that of the control sample for chickpea cultivars. Also, $K_1$ values progressively decreased with the increase in voltage and exposure time of the plasma treatment for all the six chickpea cultivars.

From Table 1, it could be seen that as the cold plasma treatment voltage increased from 40 to 60 V and treatment exposure time increased from 10 to 20 minutes for each of the six chickpea cultivars, the Peleg rate constant $K_1$ generally decreased significantly, suggesting an increase in the initial water absorption rate.

***3.2.2 Assessment of Peleg capacity constant $K_2$***

$K_2$ is a constant related to maximum water absorption capacity, i.e., the lower the $K_2$, the higher the water absorption capacity. $K_2$ values of the Peleg's model of all the plasma treated samples were higher compared to that of the control sample for all the chickpea cultivars. This may be due to increased seed coat permeability and leaching out of water from the seeds, treated with cold plasma.

for each of the six chickpea cultivars, there was no effect of plasma treatment voltage and treatment period on $K_2$.There are mixed reports on the effect of temperature on water absorption capacity of food materials, namely on $K_2$, and this depends on type of material and if soluble solids loss during soaking is considered in the calculation of moisture content of samples (**Abu-Ghannam & McKenna, 1997a).**

## 4. Conclusion

The Peleg model can be successfully used to describe water absorption of chickpea cultivars between $t_0$ and $t_\infty$. **Water absorption rate of all the chickpea cultivars seeds increased with the increase of the applied voltage (40 V to 60 V) of plasma treatment and exposure time (10 min to 20 min).**

Further, cold plasma treatment of legume seeds may be beneficial for the food industries to reduce chickpea soaking times and also aid in further processing of the legume seeds such as germination or cooking.

## References


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## NOTE:

**To avoid the lengthiness of poster and save space the figure and table details are presented of only one cultivar out of six cultivars studied Viz. Kripa.**