Soaking plasma processed chickpea (Cicer arietinum) cultivars

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Abstract
Cold plasma processing has been marched toward becoming one of the proven techno alternatives to thermal food preservation. It was found effective to cause positive alterations in the surface properties of food by etching. The effect of low-pressure cold plasma on the percent moisture absorption of six chickpea cultivars, namely, Kripa, Virat, Vishal, Vijay, Digvijay, and Rajas, was studied. For plasma treatment, low-pressure glow discharge plasma with bell-jar symmetry was employed. The samples were treated with plasma at 40, 50, and 60 W each for 10, 15, and 20 min. These were soaked in distilled water and 1% sodium bicarbonate solution at room temperature for 8 h. The percent moisture absorption changed significantly \((p < 0.05)\) with an increase in plasma power and treatment time. Kripa had the highest percent moisture absorption \((102.07 \pm 0.28)\) and \((103.31 \pm 0.68)\) at 60 W 20-min treatment while Rajas had the lowest percent moisture absorption \((78.57 \pm 0.81)\) and \((79.44 \pm 0.26)\) at 40 W and 10-min treatment in distilled water and 1% sodium bicarbonate solution soaking, respectively. The samples treated for 20 min with power 60 W showed higher moisture absorption for all the chickpea cultivars. The percent moisture absorption in control samples soaked in 1% sodium bicarbonate solution was higher than in distilled water. The same pattern did not repeat in the plasma-treated samples. The findings in this research will be useful for designing the soaking process for different cultivars of plasma-treated legumes.

KEYWORDS
chickpea, cold plasma, soaking, water absorption

1 | INTRODUCTION

Looking at the current uses of plasma processing in food preservation and processing, it seems to be a roaring technology in the field. Plasma was first described by Crookes (1879). Lewi Tonks and Irving Langmuir first coined the word “plasma.” It is the fourth state of matter that has a gas state, partly or completely ionized (Tonks & Langmuir, 1929). Cold plasma has beneficial effects, in the hydrogenation of edible oils, food allergy prevention, inactivation of anti-nutritional factors, seed germination efficiency adjustment, and effluent control (Ekezie et al., 2017). Effects of cold plasma on the seed moisture absorption have been studied by many authors (Dobrin et al., 2015; Guo et al., 2018; Li et al., 2017; Rahman et al., 2018; Roy et al., 2018; Sera et al., 2010; Sera & Sery, 2018). Ling et al. (2014) showed that plasma treatment had positive effects on seed germination and seedling growth. Physico-chemical properties of low-pressure plasma treated black gram were studied by Sarangapani et al. (2017). However, there is a scarcity of studies on the soaking characteristics of different chickpea cultivars treated with plasma processing.

Grain legumes not only occupy an important place in human nutrition, but these are the indispensable pillars of sustainable...
agriculture through the mechanism of increasing the fertility of the soil. Chickpea (*Cicer arietinum*) is the largest food legume produced in South Asia (Gaur et al., 2010). India secured the first position in chickpea production in the world with about 70% area and 67% production (FAOSTAT, 2019). Usually, legumes are soaked then cooked or else soaked then germinated or else soaked, germinated, and cooked to make them edible through softening and increasing the nutrient availability and decreasing antinutrients. Also, chickpea is soaked and cooked before processing into different products in the food industries. During soaking, the water enters into the starch granules and protein fractions of beans. This facilitates gelatinization and protein denaturation and seed gets soften (Siddiq & Uebersax, 2012). Chickpea is known to be a difficult legume to cook. The soaking is a time-consuming step, and to reduce it, attempts were made (Kon et al., 1973; Rockland & Metzler, 1967). Dried legumes are to be cooked or if they are soaked previous to cooking sodium bicarbonate and also washing soda are sometimes added in small quantities to the soaking or cooking water. This treatment softens the water and so tends to reduce soaking and cooking time (Abel, 1900). Soaking legumes in water before cooking also takes a long time to cook, while soaking in sodium bicarbonate (NaHCO₃) solution causes faster cooking and improves protein digestibility for some legumes (Vijayakumari et al., 2007). Bede (2007) studied the effects of quenching on cook ability of some food legumes. Plasma processing got much importance nowadays in food processing. The current investigation aimed to research the effects of plasma processing on soaked moisture absorption of six chickpea cultivars with soaking in distilled water and 1% sodium bicarbonate solution. The findings in this research will be further helpful to design the soaking process of plasma-treated legumes.

2 | MATERIALS AND METHODS

2.1 | Materials

Chickpea samples were procured from Mahatma Phule Krishi Vidyapeeth, Rahuri. The analytical grade chemicals needed were procured from S. D. fine chemicals and Hi-Media, Mumbai, India.

2.2 | Low-pressure glow discharge plasma system and plasma treatment

An in-house designed low-pressure glow discharge plasma with bell-jar symmetry was employed for plasma treatment. The reactor walls were made of 3-mm-thick Pyrex glass, 120 mm in height, and 300 mm in internal diameter. The base of the plasma reactor and the opening lid were made up of stainless steel. The electrodes were made up of aluminum, of 20-cm diameter. Through the Wilson seals on these plates, the electrodes were connected. The electrode distance inside the reactor was maintained at 3 cm during all the plasma treatments. A radio frequency power source with a frequency of 13.56 MHz is capacitively coupled to the device. The system pressure was initially achieved at 0.05 mBar with samples in the system by using HHV vacuum pump ED-20, and the working pressure was adjusted to an optimized value of 0.5 mBar. In this plasma reactor, the plasma glow was observed as shown in Figure 1. The plasma treatment on chickpea cultivars was carried out at 40, 50, and 60 W each having an exposure time of 10, 15, and 20 min.

2.3 | Soaking of chickpea cultivars

Approximately 8-g chickpea samples were taken into a beaker. About 50 ml of distilled water or 1% sodium bicarbonate (NaHCO₃) solution was added to it and kept at room temperature. After an interval of an hour, chickpea samples were taken out and blotted on a filter paper until the surface moisture gets removed. It was weighed and returned to the beaker. The percentage of moisture absorbed was calculated on a dry basis (Turhan et al., 2002).

2.3.1 | Statistical analysis

The findings were statistically analyzed using SPSS (IBM statistical analysis version 19) using one-way analysis of variance (ANOVA). The significance between the samples was compared at $p < 0.05$ where the least significant difference was tested by the post hoc and Duncan test. The averages from three different studies were presented in all of the findings.

3 | RESULTS AND DISCUSSIONS

3.1 | Effects of plasma treatment on soaking of chickpea cultivars in distilled water

There was a significant difference ($p < 0.05$) in moisture absorbed in distilled water soaking by the control sample and plasma treated samples in all the chickpea cultivars (Table 1). In control samples, the increase in moisture absorption was found lowest in Kripa and highest in Virat after 8 h of soaking (Table 1). The contact angle quantifies the wettability of a solid surface by a liquid. Dobrin et al. (2015) worked on the wheat grain; they found that in the case of the plasma untreated grains, the contact angle measured between grain surface and water drop was high, and in the treated grains, it decreased. They reported that after 12 min of plasma treatment, the best water absorption effect was found to be 27% greater than in untreated samples. A major precondition for faster seed wetting and germination is thus surface wetting (Sera & Sery, 2018).

The samples exposed to 40-, 50-, and 60-W power for 10, 15, and 20 min found a significant difference ($p < 0.05$) in moisture absorbed during soaking in distilled water in all the chickpea cultivars. The percent water absorption was in the range 78.57%–99.78%.
The moisture absorption was lowest at power 40 W for 10-min treatment in all the chickpea cultivars during soaking in distilled water, while it was highest at power 60 W for 20-min treatment. The increase in moisture absorption was highest in Kripa with 60 W and 20-min treatment, and it was lowest

### TABLE 1

Percent water absorption (db) of plasma-treated chickpea cultivars after soaking in distilled water and 1% sodium bicarbonate (NaHCO₃) solution

| Cultivar | Time (min) | Exposure power (40 W) | Exposure power (50 W) | Exposure power (60 W) |
|----------|------------|-----------------------|-----------------------|-----------------------|
|          | Distilled water | NaHCO₃ solution | Distilled water | NaHCO₃ solution | Distilled water | NaHCO₃ solution | Distilled water | NaHCO₃ solution |
| Kripa    | 0           | 75.65<sup>a</sup>   | 85.59<sup>d</sup> | 75.65<sup>a</sup> | 85.59<sup>d</sup> | 75.65<sup>a</sup> | 85.59<sup>d</sup> |
|          | 10          | 82.90<sup>b</sup>   | 88.88<sup>c</sup> | 89.59<sup>c</sup> | 91.84<sup>e</sup> | 90.96<sup>f</sup> | 96.03<sup>j</sup> |
|          | 15          | 89.92<sup>c</sup>   | 92.11<sup>h</sup> | 96.53<sup>c</sup> | 95.19<sup>m</sup> | 101.57<sup>p</sup> | 97.65<sup>i</sup> |
|          | 20          | 90.53<sup>d</sup>   | 94.27<sup>l</sup> | 102.15<sup>I</sup> | 101.85<sup>r</sup> | 102.07<sup>t</sup> | 103.31<sup>u</sup> |
| Virat    | 0           | 77.80<sup>d</sup>   | 85.70<sup>d</sup> | 77.80<sup>d</sup> | 85.70<sup>d</sup> | 77.80<sup>d</sup> | 85.70<sup>d</sup> |
|          | 10          | 88.68<sup>d</sup>   | 87.95<sup>b</sup> | 99.05<sup>f</sup> | 92.73<sup>l</sup> | 99.30<sup>k</sup> | 91.93<sup>j</sup> |
|          | 15          | 99.12<sup>d</sup>   | 93.37<sup>b</sup> | 100.16<sup>e</sup> | 95.53<sup>m</sup> | 100.46<sup>p</sup> | 100.09<sup>e</sup> |
|          | 20          | 99.78<sup>d</sup>   | 96.02<sup>b</sup> | 101.17<sup>e</sup> | 97.34<sup>q</sup> | 101.42<sup>p</sup> | 100.91<sup>e</sup> |
| Vishal   | 0           | 77.06<sup>b</sup>   | 81.27<sup>c</sup> | 77.06<sup>b</sup> | 81.27<sup>c</sup> | 77.06<sup>b</sup> | 81.27<sup>c</sup> |
|          | 10          | 83.61<sup>b</sup>   | 83.34<sup>d</sup> | 84.96<sup>c</sup> | 83.91<sup>e</sup> | 89.92<sup>d</sup> | 83.40<sup>e</sup> |
|          | 15          | 84.44<sup>d</sup>   | 83.49<sup>c</sup> | 86.52<sup>d</sup> | 87.56<sup>c</sup> | 93.85<sup>d</sup> | 87.57<sup>c</sup> |
|          | 20          | 84.77<sup>e</sup>   | 84.03<sup>e</sup> | 87.85<sup>e</sup> | 89.03<sup>e</sup> | 93.94<sup>e</sup> | 89.15<sup>e</sup> |
| Vijay    | 0           | 77.50<sup>d</sup>   | 81.24<sup>c</sup> | 77.50<sup>d</sup> | 81.24<sup>c</sup> | 77.50<sup>d</sup> | 81.24<sup>c</sup> |
|          | 10          | 83.56<sup>e</sup>   | 83.28<sup>d</sup> | 83.78<sup>e</sup> | 87.21<sup>e</sup> | 83.93<sup>e</sup> | 83.76<sup>e</sup> |
|          | 15          | 83.59<sup>d</sup>   | 83.47<sup>c</sup> | 84.00<sup>d</sup> | 87.51<sup>e</sup> | 84.25<sup>d</sup> | 86.56<sup>c</sup> |
|          | 20          | 84.83<sup>e</sup>   | 83.99<sup>d</sup> | 85.21<sup>d</sup> | 88.98<sup>e</sup> | 93.70<sup>e</sup> | 91.07<sup>e</sup> |
| Digvijay | 0           | 76.59<sup>b</sup>   | 78.23<sup>d</sup> | 76.59<sup>b</sup> | 78.23<sup>d</sup> | 76.59<sup>b</sup> | 78.23<sup>d</sup> |
|          | 10          | 80.43<sup>b</sup>   | 80.79<sup>d</sup> | 88.14<sup>d</sup> | 87.11<sup>e</sup> | 88.64<sup>d</sup> | 88.81<sup>d</sup> |
|          | 15          | 81.27<sup>d</sup>   | 86.42<sup>e</sup> | 89.81<sup>e</sup> | 89.82<sup>e</sup> | 92.26<sup>e</sup> | 89.60<sup>e</sup> |
|          | 20          | 86.14<sup>e</sup>   | 89.60<sup>d</sup> | 92.81<sup>g</sup> | 93.18<sup>h</sup> | 93.64<sup>e</sup> | 93.81<sup>e</sup> |
| Rajas    | 0           | 77.51<sup>c</sup>   | 78.80<sup>b</sup> | 77.51<sup>c</sup> | 78.80<sup>b</sup> | 77.51<sup>c</sup> | 78.80<sup>b</sup> |
|          | 10          | 78.57<sup>e</sup>   | 79.44<sup>e</sup> | 85.49<sup>k</sup> | 85.57<sup>f</sup> | 85.78<sup>f</sup> | 86.23<sup>e</sup> |
|          | 15          | 80.71<sup>e</sup>   | 81.63<sup>e</sup> | 86.68<sup>c</sup> | 86.57<sup>e</sup> | 87.67<sup>e</sup> | 86.85<sup>e</sup> |
|          | 20          | 87.69<sup>e</sup>   | 86.09<sup>d</sup> | 87.87<sup>e</sup> | 87.49<sup>e</sup> | 88.80<sup>e</sup> | 87.37<sup>e</sup> |

**Note:** Means with the different superscript letters in columns for each cultivar differ significantly (p < 0.05).

**Abbreviation:** W, watts; min, minutes; db, dry basis.
3.2 | Effects of plasma treatment on soaking of chickpea cultivars in 1% \( \text{NaHCO}_3 \) solution

There was a significant difference \((p < 0.05)\) in moisture absorbed in 1% sodium bicarbonate solution soaking by the control sample and plasma treated samples in all the chickpea cultivars (Table 1). In control samples, the increase in moisture absorption was found lowest in Digvijay and highest in Virat after 8 h of soaking (Table 1). Roy et al. (2018) recognized that, compared to the plasma untreated samples, the surfaces of the plasma-treated wheat grains became rough. They have correlated the enhanced water permeability in the grains with improvements in surface erosion and roughness.

The samples exposed to 40-, 50-, and 60-W power for 10, 15, and 20 min found a significant difference \((p < 0.05)\) in moisture absorbed during soaking in 1% \( \text{NaHCO}_3 \) solution in all the chickpea cultivars. The percent water absorption was in the range 79.44%–96.02%, 83.76%–101.85%, and 83.88%–103.31%, respectively, for 40, 50, and 60 W in 1% sodium bicarbonate solution soaking. The moisture absorption was lowest at power 40 W for 10-min treatment, while it was highest at power 60 W for 20-min treatment in all the chickpea cultivars during soaking in 1% \( \text{NaHCO}_3 \) solution.

The increase in water absorption was highest in Kripa with 60 W and 20-min treatment, and it was lowest in Rajas with 40 W and 10-min treatment when all the treated samples of all cultivars were compared during soaking in 1% \( \text{NaHCO}_3 \) solution (Table 1). Rahman et al. (2018) suggested that in wheat grains, which were exposed to the plasma, the surface was much rougher than that of control grains. They further added that after the plasma application, the grain coat becomes eroded and chapped.

The percent water absorption in control samples soaked in 1% sodium bicarbonate solution was higher than in distilled water. The same pattern was not repeated in the plasma treated samples. Plasma treated samples were found lacking in moisture absorption in 1% \( \text{NaHCO}_3 \) solution as compared to soaking in distilled water. This may be due to the etching, erosion of the surface of treated chickpea samples. In \( \text{NaHCO}_3 \) solution, there may be more water absorption taken place, but due to the plasma driven seed surface erosion, the absorbed moisture may get leached. It may be due to the surface etching of these samples, which causes leaching loss of moisture absorbed by these plasma treated samples (Thirumdas et al., 2016). Similar findings were reported by Sabularse et al. (1991) during their studies on the effects of gamma radiation on brown rice cooking efficiency. This suggested that there is an increase in cooking loss in plasma-treated samples compared to control samples, which may be due to the plasma species’ degradation of starch molecules. The broken starch particles are easily leached into the surrounding water during the cooking process. Filatova et al. (2014) also shown that active plasma particles produced a change in the seed coat morphology of cereal and legume seeds, which played a significant role in improving the rate of moisture absorption as it occurred in the present experiment.

4 | CONCLUSION

Looking at the all-round effects of plasma in food processing, the coming era seems to be the era of cold plasma technology. Plasma treatment increased moisture absorption significantly with an increase in plasma treatment power and time for all the six chickpea cultivars in distilled water and 1% sodium bicarbonate solution. The moisture absorption in control samples soaked in 1% sodium bicarbonate solution was found higher as compared to samples soaked in distilled water. The moisture absorption in plasma-treated samples soaked in 1% sodium bicarbonate solution...
was found less than soaking in distilled water. The major concern in the use of pulses is its long soaking and cooking time. Considering the positive effects of cold plasma on moisture absorption by chickpea, these results will surely help to save time and energy in soaking and consequent cooking of the whole chickpea.

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CONFLICT OF INTEREST
There is no conflict of interest in the authors.

AUTHOR CONTRIBUTIONS
Fayaj Pathan: data curation, formal analysis, investigation, methodology, resources, writing-original draft. Rajendra Deshmukh: methodology, resources, validation, writing-review & editing. Uday Annapure: conceptualization, resources, supervision, validation, writing-review & editing.

ETHICS STATEMENT
I hereby declare that this manuscript has not been published elsewhere, there is no conflict of interest, and all co-authors met the criteria for authorship. The study does not require any ethical approval. If any error is subsequently found in the manuscript, I will inform the journal.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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