



## Improvement in Millet Soaking by Way of Bubbled Cold Plasma Processed Air Exposure; Phytic Acid Reduction Cum Nutrient Analysis Concern

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**Abstract:** Pearl millet is one of the high-grown and underutilized grain crops. It is confined to traditional foods due to its anti-nutritional and functional properties. The present study investigated the influence of plasma processed air bubbling and soaking on phytic acid content, total and HCl extractable iron, physicochemical, techno-functional, and pasting properties of pearl millet. Exposure of pearl millet to plasma processed air bubbling at 180 V with an airflow rate of 10 liters /h for 1 h and 2 h reduced phytic acid content by 60.66 % and 39.27 % respectively. Whereas soaking for 12 h reduced phytic acid by 21.6 % in contrast with the untreated sample. The total iron content reduced from 39.9 to 29.8 mg/100g and HCl extractable iron content increased from 12 % to 69.49 % with the given treatments. Obtained data were noticed with significant changes ( $p < 0.05$ ) and are in line with its exposure to the selected variable treatments. This work points to the potentiality of plasma processed air pre-treatment in the food industry to improve nutrition and mineral availability accompanied by modifying pasting, techno-functional properties of pearl millet.

**Keywords:** Pearl Millet, Plasma Processed Air, Plasma Bubbling, Soaking, Phytic Acid.

### Introduction

Pearl millet endowed with resilience to diverse climatic conditions and gaining more attention in the present overpopulated world due to high nutritional properties [1]. It is relatively richer in fats (5-7 %), proteins (9-21 %), essential amino acid lysine (2.8-3.2 g/100g protein), and minerals such as iron (4-25.71 mg/100g) compared to most of the cereals [2-3]. Though the pearl millet is rich in minerals like iron their availability in human body is limited because of anti-nutrients like phytic acid. Phytic acid is also known as inositol hexaphosphate. It binds with divalent cations, namely  $\text{Fe}^{+2}$ ,  $\text{Zn}^{+2}$ ,  $\text{Ca}^{+2}$ , and  $\text{Mg}^{+2}$ , proteins, and results in a remarkable

reduction in their also [3]. So, it is essential to reduce the phytic acid in order to improve their in the human body [4].

Plasma is an ionized gas with a net neutral charge consisting of atoms, ions, molecules, and free electrons in the excited or fundamental state [5]. Cold plasma technology presents diverse applications such as surface decontamination, pest control, improvement of enzymatic action, antioxidant properties and alteration of functional properties of grains [6-8]. Until now, no studies have been carried out on the combination of plasma technology with conventional soaking on grains. This combination of treatments may help in maximizing the phytic acid reduction, improves HCl extractable iron, and aids in modifying the functional properties of pearl millet. As the plasma bubbled into an aqueous medium, two or more microbubble coalescence occurs and forms a macro bubble. Pressure within the bubble exceeds and causes bubble deformation, resulting in the formation of reactive species in an aqueous medium, which further affects the pH and conductivity of the medium [9,8]. The primary active species generated in plasma-treated water are hydroxyl ions (OH<sup>•</sup>), hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), Reactive nitrogen species (RNS) such as nitrous acid (HNO<sub>2</sub>), nitric acid (HNO<sub>3</sub>), and Reactive oxygen species (ROS) like singlet oxygen (<sup>1</sup>O), super dioxides (<sup>1</sup>O<sub>2</sub>), and ozone (O<sub>3</sub>) which are capable of altering food properties [9].

Present research work aimed to determine the effect of plasma processed air bubbling assisted soaking on phytic acid content and assess the changes in the total and free iron, centesimal composition, physical, techno-functional, and pasting properties of pearl millet.

## Materials and methods

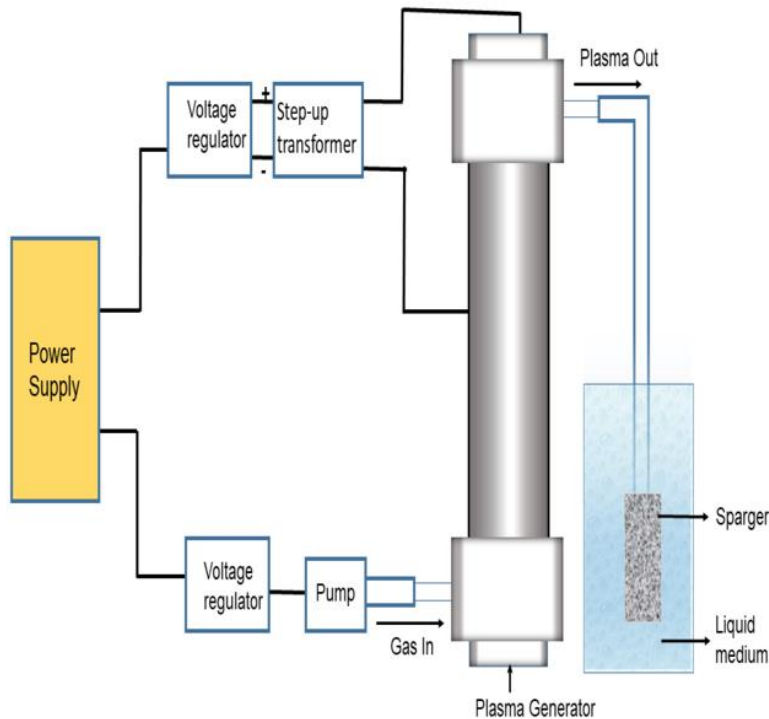
### Sample Collection

Pearl millet (*Pennisetum glaucum*) used for analysis were procured from the local market, Tamilnadu, India. Acquired pearl millet was sieved with a mechanical sieve shaker to separate whole grains from foreign matter. The cleaned grains were packed in transparent polyethylene pouches and stored at room temperature (30±2 °C).

### Plasma processed air bubbling system

A plasma bubbling system has been used to treat pearl millet [8]. A schematic diagram of the plasma bubbling setup is represented in Figure 1. The system is of dielectric barrier type comprising a hollow cylindrical tube provided with gas inlet and plasma outlet. Plasma discharge was generated using ambient air as a carrier gas; a voltage regulator controls the airflow rate and power. The plasma processed air from the unit is carried through an outlet tube and bubbled into the liquid medium using a sparger. The outlet tube was of polyurethane material with length and diameter of 250 mm and 8 mm. The atmospheric air was employed as feed gas at an input voltage of 180 V with a flow rate of 10 lph, and primary input current 0.22 A was introduced into the grains during its soaking period. Optimization of plasma bubbling system parameters such as

airflow rate, length, and outlet tube diameter was fixed based on the previous work. Since it has shown high intensity of free radicals such as OH in plasma bubbled samples [8].



**Figure 1.** Schematic diagram of the Plasma bubbling system.

### Treatment of Pearl Millet Sample

Test pearl millet sample without any pre-soaking and treatment was considered as control 1 (C1). Sample soaked for 12 h in distilled water at 1:3 (w/v) ratio was considered as control 2 (C2). The soaked sample was considered as control 2 since it is one of the most used pre-treatments in households and industries [10]. The pearl millet sample was subjected to plasma processed air bubbling treatment by immersing in distilled water at 1:3 (w/v) and bubbling plasma for 1 h (T1) and 2 h (T2). After the treatment, water was drained, and the samples were dried at 60 °C for 30 min. All samples were analyzed for phytic acid, physicochemical, techno-functional, and pasting properties. The values of control 1 was referred from the previous study of [11], which is performed with the same lot of pearl millet sample and subjected to the similar experimental pattern.

### Detection of Phytic Acid

Changes in the phytic acid content of raw and treated pearl millet samples were determined according to [12]. Phytic acid present in the sample was extracted with trichloroacetic acid and precipitated as ferric salt. Total iron content in the precipitate was estimated

colorimetrically, and the amount of phytate Phosphorus was calculated by a constant molecular ratio of 4Fe: 6P in the precipitate.

### Estimation of Total and HCl Extractable Iron

Total iron content in the pearl millet sample was determined by the wet acid digestion method. The total iron in the sample was extracted by using the mixture of nitric acid: perchloric acid (5:1 v/v) and estimated by atomic absorption spectrophotometer [13].

The HCl extractable iron in the samples (invitro bioavailability) was estimated by the method described by [13]. The sample was extracted in 0.03 N HCl and filtered by Whatman No. 42 filter paper followed by acid- digestion of extracts and determined by using atomic absorption spectroscopy.

### Centesimal Composition of the Sample

The centesimal composition of samples was analyzed by standard AOAC methods [14]. Crude fat was estimated using a Soxhlet apparatus. Crude protein was determined in terms of the percentage of nitrogen by Kjeldahl equipment, obtained nitrogen content was multiplied with a conversion factor of 6.25 for crude protein content. The crude fiber was estimated with the defatted sample followed by acid and alkali digestion. Ash content was measured as the residue after subjecting the pearl millet sample to 500 °C for 6 h. The moisture content of the sample was measured through a moisture meter (Mettler Toledo HE53, Greifensee, Switzerland). Carbohydrate content estimated from the equation mentioned below

$$100 - (\text{Crude fat} + \text{crude fiber} + \text{crude protein} + \text{ash} + \text{moisture}) \quad (1)$$

Reducing sugars were analyzed by the Dinitrosalicylic acid method [15].

### Physical Properties

Color (L, a, b) of the given sample was determined using hunter lab colorimeter (Hunter lab color flex EZ model: 45/0 LAV), and color intensity ( $\Delta E$ ) calculated from the below equation [3].

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (2)$$

Bulk density was evaluated by measuring the weight of the known volume of grains based on the procedure explained by [2].

### Techno-Functional Properties

Techno-functional properties describe the behavior of flour during processing and its impact on the finished product. Properties such as water absorption, oil absorption, water solubility, swelling power, dispersibility, and viscosity were assessed by powdering the samples to 0.5-micron size.

Water absorption and oil absorption were determined by adopting method [16]. A 10 ml of water/oil added to 1 g of powdered sample and homogenized at high speed for 30 s. Homogenate was held aside for 30 min at ambient conditions followed by centrifuging for 30 min at 3000 rpm. The obtained supernatant was measured using a measuring cylinder.

$$\text{The amount of water or oil absorbed } \left(\frac{\text{ml}}{\text{g}}\right) = \frac{\text{water or oil absorbed (ml)}}{\text{weight of the sample (g)}} \quad (3)$$

Water solubility and swelling power were analyzed, as reported by [17]. 0.5 g of sample dispersed in 10 ml of distilled water and subjected to 60 °C for 30 min. The obtained slurry was centrifuged for 10 min at 1600 rpm, and supernatant (5 ml) was evaporated using a hot air oven (Obtained value was multiplied by 2 since the 5 ml of solution was taken for measuring solubility from initially added 10 ml).

$$\text{Solubility (\%)} = \frac{\text{weight of starch after evaporating (g)}}{\text{The dry weight of the sample (g)}} \times 2 \times 100 \quad (4)$$

The 0.1 g of powdered sample was suspended in 10 ml distilled water and heated at 60 °C for 30 min with continuous stirring. The obtained mixture was centrifuged at 1600 rpm for 15 min, and the precipitate was weighed.

$$\text{Swelling power (g/g)} = \frac{\text{weight of precipitate (g)}}{\text{The dry weight of the sample (g)}} \quad (5)$$

Dispersibility was estimated, according to method. [16] The 10 g of a powdered sample was taken in a 100 ml measuring cylinder and made up to 100 ml with distilled water. Mix thoroughly, kept aside for 3 h, and volume of sedimented particles was recorded.

$$\text{Dispersibility (\%)} = 100 - \text{volume of sedimented particles} \quad (6)$$

### Pasting Properties

The pasting properties of the pearl millet samples were ascertained using a rapid visco analyzer (MCR 52, Anton Paar Co. Ltd, Austria). 3 g of powdered pearl millet sample mixed with 25 ml of distilled water and subjected to heating and cooling cycles [3]. Pasting temperature, peak viscosity, trough viscosity, breakdown viscosity, and final viscosity were obtained with the Rheoplus software.

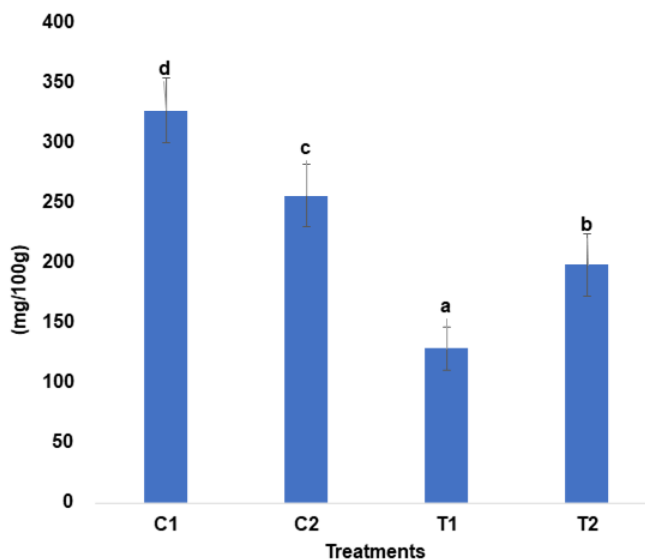
### Statistical Analysis

The data obtained were statistically evaluated by one-way analysis of variance (ANOVA) using SPSS (IBM statistical analysis of version 20.0). Duncan's multiple range test determined the significant difference at 5%. All the experiments were carried out in triplicates, and the values were presented in mean  $\pm$  standard deviation.

## Results and discussion

### Effect of Plasma Processed Air Bubbling and Soaking on Phytic Acid Content of Pearl Millet

The results revealed a significant reduction in the phytic acid content with the given treatments. Phytic acid in raw pearl millet sample C1 was found to be 327.28 mg/100g. The changes in the phytic acid content of the pearl millet sample with the given treatments are represented in Figure 2. Soaking reduced phytic acid content by 21.6 % whereas plasma processed air bubbling T1 and T2 reduced it by 60.66 % and 39.27 % respectively in comparison with C1. This result directed that plasma processed air bubbling has the ability to reduce phytic acid to a large extent.



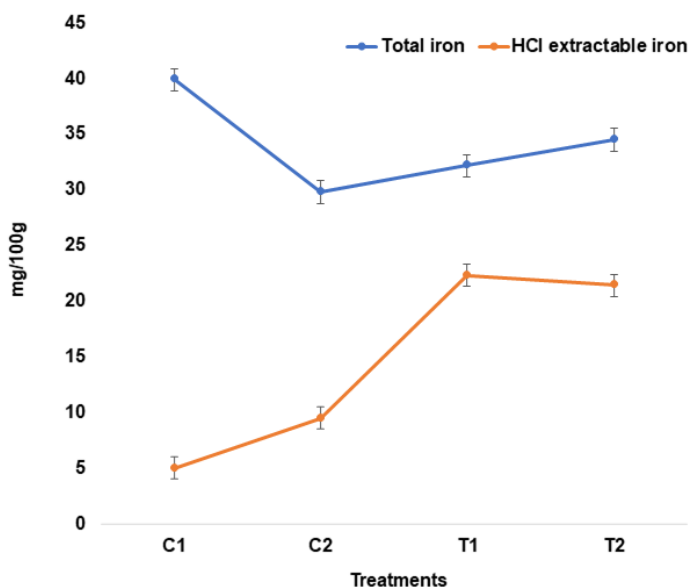
**Figure 2.** Influence of soaking and plasma processed air bubbling on the pearl millet's phytic acid content. The bars on the graph represent the standard deviation. The different letters represent a significant difference with other treatments ( $p < 0.05$ ).

The reduction in phytic acid content among the treated samples possibly due to the leaching of phytin ions into the soaked water [10]. High leaching might take place in plasma bubbling treatment due to continuous formation and disassociation of large-sized transient bubbles which facilitates an elevation in percentage of phytic acid reduction [8]. Major long live plasma reactive species such as  $H_2O_2$ ,  $O_3$ ,  $NO_3^-$  accompanied by a plethora of short live plasma radicals formed during plasma bubbling may aid in the elevation of phytin degradation [9]. Conversely, the increment of phytic acid content in T2 might be due to reabsorption of leached out phytic acid by sample because of the continuous transfer of water into grains. This

reabsorption of leached out nutrients was observed with an increase in exposure time in ultrasound treated grains [18].

### Effect of Treatments on Total and HCl Extractable Iron Content in Pearl Millet Samples

The changes in total and free iron content with the given treatments were presented in Figure 3. Untreated pearl millet sample contained high total iron of 39.91mg/100g which is reduced to 29.84 mg/100g by soaking. Moreover, plasma bubbled water treatment T1 and T2 decreased it to 32.22 and 34.53 mg/100g respectively. The reduction is due to the leaching of iron into soaked water [10]. Elevation of total iron with treatment time in T2 may be due to reabsorption of leached iron or formation of complexes with other compounds.



**Figure 3** The influence of soaking, plasma processed water treatments on the total and acid extractable iron content. The bars on the graph represent the standard error among the treatments.

The acid extractability of the iron was increased with all the given treatments. That is considered an indicator of the bioavailability of minerals in the human body [13]. A low amount of HCl extractable iron was observed in C1 i.e., 12 % possibly due to the low availability of iron in free form. Plasma processed air bubbling treatment has increased acid extractability of iron to 69.49 % and 62.17 % in T1 and T2 correspondingly. Whereas soaking improved it up to 32.03 %. An increase in the acid extractable iron content among treated samples possibly due to the decrement in phytic

acid [10]. Reduction in the free iron content was observed with exposure time in T2 which may be due to the leaching into the soaked water or forming complexes with other components in the sample.

### Centesimal Composition of Treated Pearl Millet Samples

The influence of plasma processed air and soaking on pearl millet's centesimal composition are presented in Table 1. An increase of 16 % and 17.3 % crude protein was observed by plasma processed air bubbling treatment in T1 and T2 respectively. However, an increment of 1.8 % was noticed in the soaked sample when compared with control C1. The results were consistent with the previous study, where a significant increment of protein content was observed in cold plasma treated basmati rice. This is possibly due to the action of free radicals in the plasma processed air, which contributes to an increase in the non-protein nitrogenous constituents [5]. Furthermore, the reactive oxygen species such as ozone produced during plasma bubbling have shown modifications in the quality of protein by lowering S-H groups and increasing intermolecular S-S groups altering the secondary structure of the protein [19]. This modification causes an alteration in the water and oil absorption capacities of the sample.

**Table 1.** The effect of soaking and plasma processed air on the centesimal composition and the physical properties of pearl millet grains

| Treatments | Crude protein (%)       | Crude fat (%)          | Carbohydrat c (%)       | Crude fiber (%)        | Ash (%)                | Moisture (%)            | Reducing sugars (%)    | $\Delta E$             | Bulk density (kg/m <sup>3</sup> ) |
|------------|-------------------------|------------------------|-------------------------|------------------------|------------------------|-------------------------|------------------------|------------------------|-----------------------------------|
| C1         | 11.09±0.00 <sup>a</sup> | 5.72±0.06 <sup>a</sup> | 69.44±0.10 <sup>a</sup> | 2.09±0.06 <sup>a</sup> | 1.55±0.02 <sup>a</sup> | 10.09±0.02              | 1.02±0.01 <sup>a</sup> | -                      | 0.78±0.00 <sup>a</sup>            |
| C2         | 11.29±0.01 <sup>b</sup> | 6.21±0.18 <sup>b</sup> | 67.99±0.17 <sup>b</sup> | 2.98±0.02 <sup>b</sup> | 1.25±0.01 <sup>b</sup> | 10.26±0.02 <sup>b</sup> | 1.34±0.00 <sup>b</sup> | 1.47±0.06 <sup>b</sup> | 0.75±0.00 <sup>b</sup>            |
| T1         | 12.87±0.03 <sup>c</sup> | 5.51±0.33 <sup>c</sup> | 68.04±0.26 <sup>c</sup> | 1.87±0.05 <sup>c</sup> | 1.29±0.01 <sup>b</sup> | 10.56±0.03 <sup>c</sup> | 1.71±0.02 <sup>c</sup> | 1.26±0.14 <sup>c</sup> | 0.77±0.00 <sup>c</sup>            |
| T2         | 13.01±0.01 <sup>d</sup> | 5.81±0.17 <sup>c</sup> | 66.43±0.22 <sup>c</sup> | 1.84±0.03 <sup>c</sup> | 1.33±0.01 <sup>c</sup> | 10.67±0.04 <sup>d</sup> | 2.39±0.01 <sup>d</sup> | 1.79±1.11 <sup>c</sup> | 0.76±0.00 <sup>c</sup>            |

*The data mentioned above were expressed in mean ± standard deviations of triplicate samples (on a dry weight basis). Different superscript letters in each column differ significantly from each other (p < 0.05), as evaluated by Duncan's multiple range test.*

*Treatments: C1 - raw sample. C2- 12 h soaking and T1, T2 - 1 h, 2 h plasma processed air treatment*

Plasma bubbling at different exposure times did not show any significant changes in fat concentration; meanwhile, soaking (C2) enhanced 8.5% of fat compared with control C1. This improvement is due to the rise of lipolytic enzyme activity during the soaking of pearl millet, which causes the breakdown of triglycerides and increases the concentration of simpler fatty acids [1]. Obtained results in line with findings reported by [1], who observed a 10.8 % increment in free fatty acid content in 14h soaked pearl



millet sample, furthermore a 13-20 % increment in crude lipid contents observed by [20] in soaked soybean flour.

Given treatments resulted in a 0.2 to 4.3 % decrement in carbohydrate concentration in comparison with control. The decrease in carbohydrate content during soaking and plasma bubbling might be due to the leaching of soluble carbohydrates into water or due to the formation of new components like crude fiber in the case of C2 [6]. reported changes in the structure of major carbohydrate starch with plasma exposure. The reactive species present in plasma may promote alterations by oxidation and depolymerization of amylose and amylopectin to smaller fragments. This promotes changes in functional and viscous properties of the plasma-treated sample [5].

The obtained results showed that plasma processed air bubbling treatment decreased crude fiber content, whereas soaking increased it in contrast with C1. Reduction of crude fiber in plasma-treated samples, possibly because of the degradation of complex fibrous structures formed during soaking by the action of highly active plasma species. Earlier works have reported that reactive species formed during treatment may aid in the degradation of fibrous structures [21].

Leaching of mineral components into the soaked water during treatment leads to a reduction in ash content [10]. There was a 19 % of ash content reduction in C2 and at the same time, T1 and T2 exhibited 16.7 % and 14.1 % decrement in ash content respectively. Plasma processed air bubbling treated samples have lowered ash content at initial stages due to high mineral leaching. However, an increase in ash content with exposure time possibly due to the action of plasma reactive species. Similar increment in ash content was observed in plasma treated basmati rice by [5].

Leaching of soluble components into the soaked water followed by diffusion of moisture into the millet lead to increased moisture content [22]. A significant rise ( $p < 0.05$ ) in moisture content, was observed among the given treatments. The increment was considerably high in plasma processed air treatment than simple soaking. This might result from more penetration of water molecules into the grain due to rapid bubbling action, which aids in increased leaching of components like soluble carbohydrates, minerals compared with simple soaking.

The reducing sugar content in plasma processed air bubbled and soaked samples was considerably higher than C1. The increase of reducing sugars with plasma exposure may be due to the degradation of oligosaccharides and depolymerization of starch reserves into simpler forms by the action of high-energy plasma species [7]. The study

conducted on ozone-treated flour showed a similar increment in simple sugars like glucose, fructose with a positive influence on the water solubility [23]. Besides plasma exposure, simple soaking causes enzymatic hydrolysis of starch which forms simple sugars and their derivatives resulting in improvement in reducing sugar [1].

### **Effect of Plasma Processed Air Bubbling and Soaking Physical Properties of Pearl Millet samples**

Physical properties such as color ( $\Delta E$ ), bulk density, and 1000 kernel weight of given treatments were presented in Table 1. A significant difference ( $p < 0.05$ ) in color ( $\Delta E$ ) was observed among all treatments. These deviations in treatments possibly due to the leaching of pigments or by the bleaching action of ozone gas generated during treatment [24]. The prior studies revealed that plasma exposure partially degrades pigments, phenolic compounds, and flavonoids resulting in color changes [8].

The sample's bulk density was negatively correlated with its moisture content [22]. A decrement in bulk density was observed in comparison with control C1. The imbibition of water molecules into grains during treatment results in changes in grain dimensions and leads to swelling of the grain endosperm resulting in the alteration of grain's bulk density.

### **Effect of Plasma Processed Air Bubbling and Soaking Techno-Functional Properties of Pearl Millet Samples**

The changes in pearl millet's techno-functional properties with the given treatments are represented in Table 2. The plasma bubbling T1 and T2 increased water absorption by 28.82 % and 36.03 %, whereas soaking improved it by 26.12 % in comparison with C1. On a similar note, oil absorption was observed to be increased with given treatments by 18.8 % - 28.30 % in comparison with C1. The increase in water and oil absorption with given treatments is because of changes in total protein content and the loosening of starch structures [22]. The plasma reactive species results in structural modifications of starch and protein molecules which aids in the improvement of water and oil absorption. The oxidative polymerization of starch components during plasma treatment results in connecting crystalline and amorphous regions of starch molecules and improves porosity to bind with water and oil [25]. Similar results have been observed in plasma-treated starches and ozonized whole grain flour [26, 7]. These changes can expand pearl millet flour's usage in maintaining consistency and bulking of products and can be used as a functional ingredient in sausages, toppings, desserts, etc. The rise in oil absorption also upsurges flavour retention and the mouthfeel of processed foods [27].

**Table 2.** The effect of soaking and plasma processed air on pearl millet samples' techno-functional and pasting properties.

| Parameters               | Treatments              |                          |                         |                         |
|--------------------------|-------------------------|--------------------------|-------------------------|-------------------------|
|                          | C1                      | C2                       | T1                      | T2                      |
| Water absorption (ml/g)  | 1.11±0.02 <sup>a</sup>  | 1.40±0.00 <sup>b</sup>   | 1.43±0.05 <sup>b</sup>  | 1.51±0.02 <sup>c</sup>  |
| Oil absorption (ml/g)    | 1.06±0.00 <sup>a</sup>  | 1.33±0.00 <sup>cd</sup>  | 1.26±0.05 <sup>b</sup>  | 1.36±0.04 <sup>dc</sup> |
| Swelling capacity (g/g)  | 0.23±0.00 <sup>a</sup>  | 0.31±0.00 <sup>d</sup>   | 0.28±0.00 <sup>c</sup>  | 0.25±0.00 <sup>b</sup>  |
| Solubility (g/g)         | 1.81±1.53 <sup>a</sup>  | 2.39±0.94 <sup>c</sup>   | 1.84±2.28 <sup>a</sup>  | 2.02±2.42 <sup>b</sup>  |
| Dispersibility (%)       | 72.16±0.28 <sup>a</sup> | 75.16±0.28 <sup>c</sup>  | 74.33±0.28 <sup>b</sup> | 75.83±0.28 <sup>c</sup> |
| Peak Viscosity (cP)      | 1312±10.5 <sup>a</sup>  | 1354±18 <sup>b</sup>     | 1422±21.9 <sup>c</sup>  | 1444±15 <sup>c</sup>    |
| Breakdown Viscosity (cP) | 429.7±15.9 <sup>a</sup> | 515.7±11 <sup>b</sup>    | 605.4±25.2 <sup>c</sup> | 725.6±33.4 <sup>d</sup> |
| Trough Viscosity (cP)    | 899.2±42 <sup>a</sup>   | 972.9±9 <sup>b</sup>     | 1027.1±5 <sup>c</sup>   | 1100±9 <sup>d</sup>     |
| Final viscosity (cP)     | 1782±36.77 <sup>a</sup> | 1945±33.79 <sup>bc</sup> | 1913±25.39 <sup>b</sup> | 1952±3.51 <sup>bc</sup> |
| Pasting Temperature (°C) | 75.1±0.37 <sup>a</sup>  | 73.5±0.27 <sup>b</sup>   | 73.1±0.55 <sup>b</sup>  | 72.9±0.25 <sup>b</sup>  |

The data mentioned above were expressed in mean ± standard deviations of triplicate samples. Different superscript letters in each row differ significantly from each other ( $p < 0.05$ ), as evaluated by Duncan's multiple range test.

Treatments: C1 - raw sample. C2- 12 h soaking and T1, T2 - 1 h, 2 h plasma processed air treatment

The solubility of the sample was coupled with hydrophilicity and ease of dissociation of starch granules. It represents the number of soluble components discharged from flour gel and acts as an indicator of biopolymer degradation and starch dextrinization. The plasma bubbling improved solubility with exposure time, T2 attained a maximum of 11.6 % increment in solubility. However, soaking C2 increased solubility by 32 % as compared to C1. The rise in the hydrophobic nature of the sample with soaking increases the solubility of the samples ( [22]. Apart from soaking, the major reactive species (hydrogen free radicals (OH), ozone) present in plasma processed air induce cleavage in C2-C3 glycosidic bonds and aids in improving solubility [7]. The obtained results corroborate findings, who observed a 17- 35 % increment in the solubility of rice starch with atmospheric plasma treatment [7].

Swelling power measures, the capability of starch to absorb water and swell. It reflects the extent of attractive forces present within the starch granules [22]. A maximum of 34.78 % increment in swelling power was observed with soaking in comparison with C1. A similar

increment in swelling power of soaked horse gram flour was reported by [22]. The plasma bubbling treatment reduced swelling power with an increase in exposure time, as mentioned in Table 2. A similar decrement trend was observed in plasma-treated parboiled rice flour, which was concluded as the consequence of the interaction of macromolecules like protein, lipid, or some other structural components with starch granules causing low water availability for starch granules to swell [6].

The particle size is a key factor in the dispersibility, and it plays an important role in the reconstitution of flour. Dispersibility of plasma processed air treatments followed an increment trend with exposure time, as mentioned in Table 2. In contrast, soaking increased dispersibility by 4.1 % concerning C1. This increment might be because of the interaction of reactive plasma species with the millet, which results in the high particle surface area with more reduction in size when turned into flour. The results coincided with [28], where the cold plasma treatment increased the distribution of particles, which helps in the reconstitution of flour in the beverages.

### Pasting Properties of Treated Pearl Millet Samples

Alterations in the pasting properties of pearl millet by soaking and plasma processed air treatment mentioned in Table 2. The plasma processed air bubbling and soaking lowered pasting temperature and improved peak, trough, breakdown, and final viscosity.

Pasting temperature indicates the temperature at which the viscosity rapidly upsurges during the heating process. High pasting temperature (PT) was noticed in C1 might be due to the existence of starch with low swelling and resistance to rupturing [25]. A significant reduction ( $p < 0.05$ ) in pasting temperature was observed with the given treatments. This might be due to the rise in the hydrophilic nature of the sample with the given treatments which enables easy penetration of water resulting in reduced PT [29]. Peak viscosity (PV) is attained by gelatinized starch during heating. It is an indicator of the thickening behavior of starch [25]. The PV significantly improved ( $p < 0.05$ ) with the soaking and plasma processed air bubbling. The plasma treatment induces loosening or damage of starch granules, weakens bond strength resulting rise in PV [6]. Trough viscosity of the samples also followed a similar increment pattern as PV.

The disintegration of gelatinized starch causes breakdown viscosity (BV), and it indicates the shear-thinning property of the sample [30]. The plasma processed air treatment and soaking resulted in a significant improvement ( $p < 0.05$ ) in breakdown viscosity. Final viscosity (FV) discloses the sample's capability to form a viscous paste [30]. FV was found to be increased with given treatments in comparison with C1. Improvement in final viscosity was because of the retrogradation and reformation of starch in the pearl millet flour during cooling. The plasma reactive species loosens the structure of starch granules resulting in leaching of starch components, which leads to a rise in viscosity. This increase in viscosity helps formulate thick sauces and soups [7, 27].

## Conclusion

The effect of plasma processed air bubbling on pearl millet properties was investigated in the present study. The maximum reduction in phytic acid content was observed with one-hour plasma processed air bubbling treatment. The total iron content of the pearl millet sample was reduced with treatments and the HCl extractable iron increased up to 69.4 % with the given treatments. Moreover, techno-functional properties and pasting properties have significantly increased with plasma processed air exposure ( $p < 0.05$ ), which positively expands the usage of pearl millet in sausages, desserts, whipped toppings, sauces, soups, etc. Simultaneously, the samples' swelling index fluctuated with treatment and exposure time due to the action of reactive plasma species. This study highlights the possibility of plasma processed air bubbling on the improvement of pearl millet's nutritional value its utilization in various convenience products.

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