Effect of low temperature plasma on the functional properties of basmati rice flour

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Abstract The present study deals with the application of low temperature plasma on basmati rice flour and its effect on functional properties such as gel hydrations properties, flour hydration properties, gelatinization temperatures and antioxidant properties. The water holding capacity and water binding capacity were observed to be increased with increase in plasma power and time of treatment as the air plasma is known to make the surface more hydrophilic. XRD analysis revealed there is no significance difference in the crystalline structure after the plasma treatment. DSC shows a decrease in peak temperatures (T_p) after the treatment. Hot paste viscosities were observed to be decrease from 692 to 591 BU was corresponded to decrease in peak temperature. The total polyphenolic content and reducing power was observed to be increased. The effects of plasma treatment on functional groups of polyphenols were observed by changes in absorption intensities using FTIR. This study demonstrates that the low temperature plasma treatment is capable of improving the functional properties of basmati rice.

Keywords Low temperature plasma · Rice flour · Depolymerization · Hydrophilicity · Phenolic compounds

Introduction

The term ‘Plasma’ was first employed by Irving Langmuir in 1928 to define this fourth state of matter which is partially or fully ionized state of gas and discovered plasma oscillations in ionized gas (Langmuir 1928). Plasma processing has been used for sterilization, functionalization, altering the hydrophilic/hydrophobic properties, etching or deposition of thin films etc. (Misra et al. 2014, 2015; Thirumdas et al. 2015a). Air plasma are excellent sources of reactive oxygen-based and nitrogen-based species, such as O, O₂, O₃, OH, NO, NO₂ (Laroussi 2009). Schutze et al. (1998) reported that the density of charged species in low pressure plasma discharge is around 10^8 – 10^{13} cm⁻³. Thirumdas et al. (2015a) reported that the application of cold plasma is an alternative technology used for the dry etching surface modification of biopolymers. The active species present in the plasma environment are responsible for initiating chemical reactions leading to modifications like (1) formation of network in polymer chains called crosslinking, (2) reduction in molecular weight by chain scission and (3) polymerizing a monomer and grafted onto the base polymer chain called grafting (Sarma 2005).

Rice (*Oryza sativa* L) is the staple foods for nearly half of the world's population and second leading cereal in production. Asian people get 60 % of calories from the consumed food through cereals (Itagi and Singh 2015). Paddy rice, after harvesting, is either used as milled raw rice or further processed into parboiled rice (Abdul et al. 2011). Starch is a major component of rice and its functionality is determined by its water binding capacity, gelatinization temperature, paste clarity, paste viscosity, solubility, swelling power, retrogradation behavior and gel properties (Adebawale and Lawal 2002). The functional properties determine the behavior of nutrients in foods

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during processing, storage and preparation as they affect food quality and acceptability. The phenolics like ferulic acid and diferulate are predominant in rice grains. Kalita et al. (2014) reported that there is need to be more attention towards the functional properties of starch due to increase in the textural expectation of the consumers. Changes in the functional properties of rice were long attributed to the changes occurring in rice chemical composition due to various processing of rice (Saleh and Meullenet 2015). The main objective of this research is to study whether low temperature plasma can cause significant changes in functional properties of rice flour for better utilization. The effect of low temperature plasma on functional properties such as gel hydrations, gelatinization, thermal properties and antioxidant properties etc. were evaluated after the plasma treatment.

Materials and methods

Materials

Basmati rice was used for analysis which is procured from local market. The basmati rice used was fully polished rice. All required chemicals were procured from SD fine chemicals and Hi-Media laboratories (Mumbai), India. All chemicals and reagents used were of analytical grade.

Sample preparation

In order to expose maximum surface of the rice grains to plasma environment, rice grains were coarsely ground to pass through 40 mesh sieve. In order to avoid sucking of fine rice flour particles along with the air during vacuum generation instead we used coarse rice grains (40 mesh size). After plasma treatment, the sample was further grounded to 80 mesh to obtain fine flour. Hence forth, this fine flour is named as “plasma treated basmati rice flour”.

Plasma apparatus

Plasma reactor made of a glass tube having thickness 4 mm, height 120 mm and internal diameter 300 mm was used for this purpose. A schematic diagram of the bell jar type plasma reactor used in the present study is given in Fig. 1. The reactor has top and base plate made of stainless steel. The electrodes were connected through the Wilson seals on these plates. The base plate has ports to connect gas/monomer reservoir, pirani gauge, vacuum pump, air admittance valve etc. The diameter of the two parallel electrodes was 20 cm and distance between the electrodes was kept constant (3 cm) in all the experiments. A thin layer of coarsely ground rice flour was placed in a petri

Fig. 1 Schematic diagram of bell jar type plasma reactor

dish and kept in between the two electrodes. Initially, the system was evacuated to 0.05 mbar using Edward's rotary vacuum pump to remove adsorbed gases or water vapours from the surface of the coarsely ground rice flour. The untreated sample was also kept in vacuum before characterization. Atmospheric air was used as gas for plasma generation and the working pressure was then adjusted to 0.15 mbar using mass flow controller. Electrodes were capacitively coupled to radio frequency (RF) power supply having frequency 13.56 MHz. The matching network was adjusted to get stable glow discharge. Coarsely ground rice flour was subjected to air plasma treatment at two different power levels and for different durations. The treated samples were kept in zip lock polythene bags (40 μ m) and stored in a desiccator at room temperature till further analysis. The samples were treated at two different power levels 30 and 40 W at different time intervals and samples were designated as untreated sample (vacuum applied without plasma treatment), sample 1 (30 W, 5 min), sample 2 (30 W, 10 min), sample 3 (40 W, 5 min), sample 4 (40 W, 10 min).

Proximate composition

Moisture, fat, protein, and ash, was determined using (AOAC 2010) methods. Carbohydrate content was determined by difference.

Gel hydration properties

Water absorption index (WAI), water solubility index (WSI) and swelling power (SP) of treated and untreated rice flour were determined following the method given by Rosell et al. (2011) with slight modifications. A (50.0 $\pm$ 0.1 mg) sample (W_i) was dispersed in 1.0 ml of distilled water in an pre-weighted eppendorf tube using a wire rod and cooked at 90 $^{\circ}$ C for 10 min in a water bath. The cooked paste was cooled in an ice water bath for

10 min, and then centrifuged at $3000\times g$ at $4\text{ }^{\circ}\text{C}$ for 10 min. The supernatant was decanted into pre-weighted small glass vials and the weight of dry solids was recovered by evaporating the supernatant at $105\text{ }^{\circ}\text{C}$ till constant weight. Five replicates were made for each sample. Residues (W_r) and dried supernatants (W_s) were weighed and WSI, WAI and SP were calculated as follows:

$$\text{WAI}(\text{g/g}) = W_r/W_i$$

$$\text{WSI}(\text{g}/100\text{ g}) = W_s/W_i \times 100$$

$$\text{SP}(\text{g/g}) = W_r/(W_i - W_s)$$

Flour hydration properties

The water holding capacity (WHC) defined as the amount of water retained by the sample without being subjected to any stress was determined mixing flour with distilled water (10 ml) and kept at room temperature for 24 h.

Water binding capacity (WBC) defined as the amount of water retained by the sample under low-speed centrifugation was determined by the method of de la Hera et al. (2013). Samples were mixed with distilled water (10 ml) and centrifuged at $2000\times g$ for 10 min. WBC is expressed as grams of water retained per gram of solid.

Oil holding capacity (OHC), the method of de la Hera et al. (2013) was followed. Rice flour ($100.0 \pm 0.2\text{ mg}$) was mixed with 1.0 ml of vegetable oil. The content was stirred for 1 min with a wire rod to disperse the sample in the oil. After a period of 30 min in the vortex mixer, tubes were centrifuged at $3000\times g$ and $4\text{ }^{\circ}\text{C}$ for 10 min. The oil holding capacity is expressed as grams of oil bound per gram of the sample.

Aroma of basmati rice

The aroma of basmati rice flour was done according to the procedure given by Sood and Siddiq (1978).

Thermal properties

The thermal analyses of different treated basmati rice were conducted using a Q2000-DSC (TA Instruments, New Castle, DE, USA), according to Yu et al. (2015) with slight modification. The samples were prepared by mixing 5 mg each of sample and 10 mg distilled water in aluminum pans and keeping for 1 h at $4\text{ }^{\circ}\text{C}$. An empty indium pan was used as a reference. The pans were hermetically sealed and heated at $5\text{ }^{\circ}\text{C}/\text{min}$ from 30 to $130\text{ }^{\circ}\text{C}$ under N_2 atmosphere.

Pasting profiles

A 12 % (w/v) slurry of flour taken in the bowl of the amylograph was heated to raise temperature from 30 to $92\text{ }^{\circ}\text{C}$ at rate $7.5\text{ }^{\circ}\text{C}/\text{min}$, holding at $92\text{ }^{\circ}\text{C}$ for 1 min, cooled to $50\text{ }^{\circ}\text{C}$ at the same rate. The changes were recorded in a microbrabender viscoamylograph.

X-ray diffraction analysis

X-ray diffractograms were obtained with an X-ray diffractometer under operating conditions as follows: the X-ray generator was operated at 40 kV and 40 mA, and the scanning angle 2θ was set from 4θ to 40θ at a scanning rate of 0.1 min^{-1} (Bello et al. 2015).

Antioxidant properties

The crude phenolic compounds present in rice fractions were extracted with methanol and water (70:30 v/v) at room temperature with shaking at 150 rpm for 4 h. The mixtures were centrifuged at 5000 rpm for 10 min and the supernatants were collected and used for further analysis. Total phenolic content (TPC), free-radical scavenging activity on DPPH, reducing power were determined by methods reported by Sreeramulu et al. (2009). Total antioxidant capacity (TAC) was measured by spectrophotometric method given by Prieto et al. (1999). Ascorbic acid equivalents were calculated by plotting standard graph of ascorbic acid.

Fourier Transform Infrared spectroscopy (FTIR)

KBR-rice flour pellet was prepared as per the procedure given by Falade et al. (2014). 5 mg of rice flour sample was mixed with 195 mg of infra-red grade potassium bromide (KBR) and pressed using a manual press for 20 min to obtain a transparent pellet. The pellet formed was transferred into the FTIR system (Bruner) and spectra were obtained in transmittance (%) mode from 400 to 4000 cm^{-1} .

Statistical analysis

The results were statistically analyzed by one-way ANOVA using SPSS (IBM statistical analysis Version 19). Duncan's new multiple-range test was used to determine significant differences. Statistical significance was given at $P < 0.05$ post hoc comparison, SPSS 19 version.

Results and discussion

Proximate composition of basmati rice flour

The proximate composition of control and plasma treated rice flour samples were given in Table 1. Moisture content of control sample was found to be decreased from 10.28/100 g (fresh weight) to 7.55/100 g due to application of vacuum system which removes the moisture from the surface of rice. The moisture content in plasma treated sample was also found to be decreased from 7.55 to 7.00/100 g which may be due to formation of oxygen radicals formed by decomposition of water molecule as reported by Zou et al. (2004) in the modification of starch by glow discharge plasma. We believe that plasma treatment facilitates the loss of moisture from the surface due to etching. It was further observed that the moisture decreases with increase in plasma power and treatment time. Similar decrease in moisture content was found in plasma treated granular starches in low pressure gas plasma (Lii et al. 2002). The decrease in moisture content can be also explained in other possible mechanism as reported by Deeyai et al. (2013) that the dissociated water molecules are engulfed into the starch structure that can be easily observed from the peaks of FTIR at 1630 and

3272 cm^{-1} . It was also reported that the absorption of water by starch structure by two ways a tight bond at 1630 cm^{-1} and a weak absorption at 3272 cm^{-1} and it resulted in cross linking of starch molecules. Protein content of control sample was found to be 5.37/100 g and varied among treated samples from 5.44 to 5.55/100 g. Ash content after plasma treatment was slightly increased from 0.35 to 0.37/100 g. There was no significant difference ($P > 0.05$) in fat and carbohydrates content of samples after the plasma. We observed that the plasma treatment has no significant change in its proximate composition of rice flour. Similar results were reported in plasma treated brown rice (Chen et al. 2012; Chen 2014; Thirumdas et al. 2015b).

Gel hydration properties

The water uptake during thermal treatment includes gelatinization of starch and protein denaturation, which is assessed by determining the water absorption index, solubility index and swelling power (de la Hera et al. 2013). Gel hydrations properties of plasma treated rice flour were significantly affected by plasma treatment as shown in Table 2. Sample 4 was observed to have highest WAI (11.97 g g^{-1}), whereas untreated sample with lowest value

Table 1 Proximate composition of basmati rice flour (g/100 g)

Parameter	Treatment				
	Untreated	30 W 5 min	30 W 10 min	40 W 5 min	40 W 10 min
Moisture content	7.55 $\pm$ 0.07 ^c	7.29 $\pm$ 0.01 ^b	7.05 $\pm$ 0.06 ^a	7.22 $\pm$ 0.03 ^b	7.00 $\pm$ 0.01 ^a
Protein content	5.37 $\pm$ 0.01 ^a	5.44 $\pm$ 0.02 ^b	5.53 $\pm$ 0.02 ^c	5.50 $\pm$ 0.04 ^c	5.55 $\pm$ 0.04 ^c
Fat	0.50 $\pm$ 0.01 ^a	0.51 $\pm$ 0.04 ^b	0.51 $\pm$ 0.01 ^b	0.51 $\pm$ 0.001 ^b	0.52 $\pm$ 0.001 ^c
Ash	0.35 $\pm$ 0.01 ^a	0.37 $\pm$ 0.01 ^c	0.36 $\pm$ 0.01 ^c	0.36 $\pm$ 0.01 ^c	0.35 $\pm$ 0.01 ^b
Carbohydrates	86.24 $\pm$ 0.02 ^b	86.4 $\pm$ 0.05 ^a	86.55 $\pm$ 0.04 ^a	86.42 $\pm$ 0.01 ^a	86.58 $\pm$ 0.01 ^a

All the data are expressed as mean $\pm$ SD. Means with the different superscript letters in a row are differ significantly ($P < 0.05$)

Table 2 Gel and Flour hydrations properties of plasma treated basmati rice flour

Parameter	Treatment				
	Untreated	30 W 5 min	30 W 10 min	40 W 5 min	40 W 10 min
Gel hydration properties					
Water absorption index (g/g)	10.05 $\pm$ 0.06 ^a	10.26 $\pm$ 0.02 ^b	11.08 $\pm$ 0.03 ^d	10.39 $\pm$ 0.03 ^c	11.97 $\pm$ 0.04 ^e
Solubility index (%)	5.30 $\pm$ 0.05 ^a	5.38 $\pm$ 0.04 ^b	6.35 $\pm$ 0.02 ^d	5.41 $\pm$ 0.02 ^c	7.33 $\pm$ 0.05 ^e
Swelling power (g/g)	10.77 $\pm$ 0.02 ^a	10.84 $\pm$ 0.03 ^b	11.86 $\pm$ 0.06 ^d	11.24 $\pm$ 0.05 ^c	12.72 $\pm$ 0.04 ^e
Flour hydration properties					
Water holding capacity (g/g)	2.23 $\pm$ 0.01 ^a	2.30 $\pm$ 0.01 ^b	2.39 $\pm$ 0.02 ^c	2.31 $\pm$ 0.02 ^b	2.43 $\pm$ 0.01 ^d
Water binding capacity (g/g)	2.02 $\pm$ 0.01 ^a	2.19 $\pm$ 0.02 ^b	2.36 $\pm$ 0.05 ^c	2.20 $\pm$ 0.02 ^b	2.46 $\pm$ 0.04 ^d
Oil holding capacity (g/g)	1.83 $\pm$ 0.01 ^b	1.98 $\pm$ 0.02 ^c	1.67 $\pm$ 0.1 ^a	1.79 $\pm$ 0.13 ^{ab}	1.68 $\pm$ 0.02 ^a

All the data are expressed as mean $\pm$ SD. Means with the different superscript letters in a row are differ significantly ($P < 0.05$)

(10.05 g g⁻¹). WAI of plasma treated sample was found to be increased with increase in plasma power and time of treatment. WAI is a result of degree of disintegration of native starch granules and it is also stated that undamaged starch granules results in lower values of WAI (de la Hera et al. 2013). Ishikawa and Ito (2004) reported that plasma can induce the depolymerization of starch and carboxylic starch formed by partly oxidization. Due to damage caused by plasma reacting species on the rice flour particles, it resulted in more WAI in treated rice samples.

Solubility index and swelling power are the properties depend on the starch species and the type and the substitution groups (Qin-Lu et al. 2011). Solubility index of sample 4 was found to be highest (7.33 %), whereas lowest value was observed in untreated sample (5.3 %). The increase in solubility values shows that there is a significant effect of plasma species on the rice flour. Similar results were reported in starch treated with gamma irradiation (Nemtanu and Brasoveanu 2010). The solubility is associated with the hydrophilicity and ease of disruption of the starch granules (Qin-Lu et al. 2011). Plasma treatment creates rougher morphology on the surface of rice grains thereby increasing in the effective area for contact and it is also well known that air plasma treatment results in increase in hydrophilic nature (Pandiyaraj et al. 2009).

Swelling power measures the magnitude of the interaction between starch chains within the amorphous and crystalline domains, which was influenced by the amylose to amylopectin ratio in terms of molecular weight, distribution, degree of branching, branch length and conformation (Pal et al. 2016). Swelling power was found to be significantly increased after the plasma treatment. Swelling power was found to be increased with increase in plasma power and time of treatment. The results were in agreement with those reported by Pal et al. (2016) in the nonthermal plasma treated rice grains. The increase in solubility index and swelling power can also be explained by the surface etching and depolymerization of amylopectin side branches caused by the energetic plasma species, which facilitates easy leach out of amylose particles during cooking which leads to increase in amount of supernatant resulting in increase in swelling power and solubility index. It was observed that there is a significant difference ($P < 0.05$) in gel hydration properties after the plasma treatment.

Flour hydrations properties

Flour hydrations properties of plasma treated basmati riceflour are given in Table 2. WBC was found to be increased after the plasma treatment which was found to be highest in sample 4 (2.46 g g⁻¹) and lowest in untreated sample (2.02 g g⁻¹). The increase in WBC

content is may be due to change in surface structure of rice facilitated easy absorption of water as plasma known to cause surface etching when exposed. Chen et al. (2012) reported that plasma treatment caused ‘etching or ablation’ on the surface of plasma treated brown rice. Similar trend was also observed in WHC, found to be increased in treated sample than in untreated samples. Sample 4 containing highest WBC was also found to have highest WHC (2.43 g g⁻¹) these results are in agreement with de la Hera et al. (2013). The increase in flour hydration properties in plasma treated samples was due to the increase in capillary action and surface energy. Hence, there is an increase in the amount of water uptake due to plasma treatment. Grzegorzewski et al. (2010) also observed increase in capillary rise and surface energy after the plasma treatment to the lamb lettuce leaves. de la Hera et al. (2013) reported that OHC was used to determine the capacity of flour proteins to bind fat by capillary action. Though the sample 1 shows marginal increase in OHC when compared to control sample and there is no significant difference was observed for other treated samples, which may be correlated with the data obtained from proximate analysis showing marginal change in protein content. This may be attributed to the fact that OHC is primarily due to the physical entrapment of oil within the starch structure, since starch does not possess non-polar sites akin to those found in proteins. The mechanism of oil holding may be explained as a physical entrapment of oil related to the non-polar side chains of proteins (Abu et al. 2006).

Aroma of basmati rice

The novel method proposed by Sood and Siddiq for the aroma determination of rice was used for decades by the breeders. The characteristic aroma was determined by placing rice in petri dish along with dilute alkaline solution and the evolved aroma was inhaled by the nose. This method was furthered standardized that the concentration and volume of alkaline solution and amount of sample used play an important role in the aroma evolution (Vasudeva et al. 1986). In our case, we observed that there is decrease in the characteristic aroma evolved after the plasma treatment. This is may be due to application of vacuum that potentially sucked away the aroma of the rice flour or breakdown of the aromatic compound present in the rice by the energetic plasma species.

X-ray diffraction analysis

The normal rice shows A-type pattern, the similar type pattern was observed in the present investigation but the intensity of peak was reduced in the plasma treated rice

Fig. 2 X-ray diffractograms for plasma treated and untreated samples rice flour. *a* Untreated, *b* sample 1 (30 W 5 min), *c* sample 2 (30 W 10 min), *d* sample 3 (40 W 5 min), *e* sample 4 (40 W 10 min)

samples. Similar results have observed by Pal et al. (2016) in the nonthermal plasma treated rice flour. The reduction of peaks may be due to depolymerization of starch occurred due to plasma treatment (Lii et al. 2002). The results indicated that the intensity of reflections at 2θ was found different in different samples. Similar type of decrease in intensity of peaks has also been reported by Zhang et al. (2013) during the application of oxygen plasma to the starch. From the Fig. 2 the intensity of peaks was found to be sharp in control samples and it became blunt in plasma treated samples. There is no difference in 2θ for peaks in treated and untreated samples. The bombardment of high energetic plasma species caused depolymerization of starch led to de-crystallization of rice flour after the treatment. Wongsagonsup et al. (2014) reported that the application of jet atmospheric argon plasma on tapioca starch caused depolymerization of starch granules. Although there is less effect of plasma on the crystalline structure of rice this may be due to plasma is a surface phenomenon. Similar decrease in crystallinity after the plasma treatment was observed in brown rice (Chen 2014; Pal et al. 2016).

Thermal properties

Gelatinization phenomenon of starch is an irreversible phase transition associated with transformation of crystalline phase into amorphous phase, which is responsible for different functional properties. The gelatinization initially occurs in the amorphous regions because hydrogen bonding is weakened in this amorphous region. The endothermic curves of plasma treated samples by DSC are shown in Fig. 3. The untreated and sample 1 was observed to have similar peak temperature (84 °C) followed by sample 3 (81.2 °C), sample

2 (74.5 °C), whereas sample 4 with lowest peak temperature (68 °C). The decrease in peak temperature after the plasma treatment may be due to de-crystallization of starch caused by the energetic plasma species (Lii et al. 2002; Wongsagonsup et al. 2014). The peak temperature (T_p) was observed to be decreased with increase in plasma power and treatment time. These results are in agreement with the finding reported by Chen (2014), where it was stated that peak temperature was decreased after the exposure of brown rice to air plasma. The decrease in peak temperature can also be explained by reduction in degree of crystallinity of rice after the plasma treatment (Chen 2014; Sarangapani et al. 2015; Thirumdas et al. 2015b).

Pasting properties

Pasting properties are significantly important in determining the behavior of starch during and after cooking. The pasting characteristics could be attributed to variation in amylopectin molecular structure rather than amylose (Juliano et al. 1987). The peak viscosity is the maximum viscosity attained by gelatinized starch during heating in water. Breakdown viscosity measures the vulnerability or susceptibility of the cooked starch to disintegration. Higher the breakdown viscosity, the lower the ability of the starch sample to withstand heating and shear stress during cooking (Adebawale et al. 2005). Pal et al. (2016) reported that the amino acids content of the rice protein can also influence the paste viscosity and breakdown viscosity. The observed decrease in the breakdown viscosity may be due to changes in the amino acids content. Setback viscosity was also found to be decreased after the plasma application. Setback viscosity is related to the retrogradation

Fig. 3 Differential Scanning calorimeter thermograms of rice flours (A, Untreated; B, 30W 5 min treated; C, 30W 10 min treated; D, 40W 5 min treated; E, 40W 10 min treated)

tendency of the product. Setback viscosity is a useful index in the prediction of storage life of product prepared from flour (Zaidul et al. 2007). Table 3 shows the brabender viscoamylograph results of the plasma treated basmati rice flour. In plasma treated samples the hot paste viscosity and final viscosity was found to be decreased with increase in plasma power and treatment time. The Hot paste viscosity was found to be 692 BU in untreated sample and it was decreased to 551 BU for sample 4. The final viscosity (the viscosity at the end of test after cooling to 50 °C) was also found to be decreased to 947 BU from 1260 BU. Wongsagonsup et al. (2014) reported that the two competitive reactions takes place due to application of plasma that is cross linking and depolymerization of starch. The changes in pasting properties after the plasma treatment may be due to the breakdown of amylopectin side chains resulting in changes in morphology of the starch granules. The high rate of decrease in viscosity of sample 4 was may be due to higher fragmentation of starch by high plasma intensity. The similar decrease in viscosity is also observed in gamma irradiated starch (Nemtanu and Brasoveanu 2010).

Antioxidant properties

Total phenolic content was found to be increased due to plasma treatment as per the data shown in Table 4. Sample 1 (0.53 mg g^{-1}) was observed to have highest TPC content and lowest concentration in control sample (0.435 mg g^{-1}). Adom and Liu (2002) reported that photochemicals particularly polyphenols exist in two forms such as free and inbound especially binding to cell wall materials. Acosta-Estrada et al. (2014) proposed that in rice 62 % of phenolics were available in bound form. As the plasma affects the surface particularly cell wall layers, which is responsible for the disruption of cell wall releasing the inbound polyphenols. This may be responsible for the increase in polyphenols content in treated samples compared to untreated sample. These results of increase in the total phenolic content were found to be similar with the finding of chemical composition of plasma treated lamb lettuce leaves (Grzegorzewski et al. 2010). Similar trend was observed for total antioxidant capacity and reducing power in plasma treated samples. TAC was ranged from 0.62 to 0.86 mg g^{-1} , while sample 1 was found to be highest (0.86 mg g^{-1}) and least concentration was observed in

Table 3 Pasting properties of plasma treated basmati rice

Treatment	Parameter			
	Hot paste viscosity (BU)	Final viscosity (BU)	Break down viscosity (BU)	Setback viscosity (BU)
Untreated	692 ± 7.70^d	1260 ± 9.19^d	22 ± 2.12^b	568 ± 5.65^e
30 W 5 min	670 ± 10.6^c	1044 ± 31.1^b	28 ± 1.20^c	406 ± 7.07^b
30 W 10 min	598 ± 12.3^b	1029 ± 14.1^b	13 ± 4.94^a	422 ± 12.7^c
40 W 5 min	664 ± 3.50^c	1185 ± 6.36^c	19 ± 3.67^b	522 ± 5.65^d
40 W 10 min	551 ± 5.56^a	947 ± 12.02^a	12 ± 5.07^a	378 ± 16.26^a

All the data are expressed as mean $\pm$ SD. Means with the different superscript letters in a row are differ significantly ($P < 0.05$)

Table 4 Antioxidant properties of plasma treated basmati rice flour

Parameter	Treatment				
	untreated	30 W 5 min	30 W 10 min	40 W 5 min	40 W 10 min
Total phenolic content (mg GAE/g)	0.44 ± 0.03 ^a	0.53 ± 0.01 ^c	0.50 ± 0.01 ^{bc}	0.49 ± 0.01 ^{bc}	0.48 ± 0.02 ^b
Total antioxidant capacity (mg/g)	0.63 ± 0.04 ^{ab}	0.86 ± 0.05 ^e	0.74 ± 0.01 ^c	0.84 ± 0.01 ^d	0.69 ± 0.04 ^b
Reducing power (mg/g)	0.54 ± 0.01 ^a	0.60 ± 0.02 ^b	0.78 ± 0.01 ^c	0.57 ± 0.05 ^b	0.62 ± 0.03 ^b

All the data are expressed as mean ± SD. Means with the different superscript letters in a row are differ significantly ($P < 0.05$)

untreated sample (0.62 mg g⁻¹). It was observed that with increase in plasma power there is increase in the antioxidant properties. After the plasma treatment reducing of Fe⁺³ to Fe⁺² was increased and showed a significant change. The increase in reducing power is a may be due to increase in total polyphenols and both can be highly correlated. Hinneburg et al. (2006) reported that the iron (III) reducing activity is correlated with the content of total phenols.

DPPH free radical scavenging activity of different treated samples was analyzed. The % inhibition activity was found highest in sample 4 (41.4 %), followed by sample 2 (38.5 %), sample 3 (33.8 %), sample 1 (30.2 %) and lowest in control sample (28 %). The increase in antioxidant properties after plasma treatment is due to immanent species of plasma releases the bounded phenolic compounds as plasma reaches the granular interior located closely to the surface which are released during extraction process. The increase in antioxidant properties may also be due to the presence of UV radiations during the plasma generation resulting in formation of secondary metabolites particularly polyphenols and flavonoids. Due to the surface etching caused by the reacting species of plasma which easily facilitates penetration of UV radiations into the cells this may enhance the synthesis of these secondary metabolites. Several studies reported that plants exposed to artificial UV-B radiations showed changes in the flavonoids biosynthesis pathway (Harborne and Williams 2000; Grzegorzewski et al. 2010).

Fourier Transform Infrared spectroscopy

FTIR was used to study the changes in functional groups after the plasma treatment of rice flour. The intensity of peak at 1019 cm⁻¹ was observed to be more in plasma treated samples when compared to untreated samples. The functional group found at that wave number is carboxylic acid and the bond type is C=O stretch. The absorbance intensity was found to be 0.158 units for control sample and it was increased to 0.304 units in sample 4. Kalita et al. (2014) reported that the starch modified by cross linking using vinyl acetate found that there is increase in C=O stretching at 1016 to 1017 cm⁻¹. Several reports confirmed

that application of plasma can leads to cross linking of starch (Lii et al. 2002; Deeyai et al. 2013; Wongsagonsup et al. 2014). Similar results were also reported by Nemtanu and Brasoveanu (2010) when starch treated by gamma irradiation indicates the formation of chemical groups with acidic character such as carboxyl, carbonyl or peroxide groups. The peaks around 1641–1737 cm⁻¹ corresponds to the C=O stretching attributed by the phenols of the hemi-celluloses and lignin (Daffalla et al. 2010). The absorption intensity at the 1654 cm⁻¹ was increased from 0.434 units in untreated sample to 0.583 units in sample 4 indicative of C=C stretch of the alkenes and aromatic functional groups. There is also increase in absorbance intensity at 2928 cm⁻¹ in plasma treated sample. The type of bond found at that wave number is due to O–H bending vibrations. It is also observed there is extension in broadness in the band at 3401 cm⁻¹ due to the vibrations of hydroxyl groups. It was already stated that there is increase in absorption of hydroxyl groups into the starch molecules during the plasma treatment (Deeyai et al. 2013).

Conclusions

The significant changes in the functional properties of basmati rice were observed due to low temperature plasma treatment. Gel hydration properties and flour hydration properties are increased resulting in the positive effect after treatment. Plasma treatment facilitates the release of bound phenolic compounds during extraction process, which in turn increases antioxidant properties. Therefore, it can be concluded that the use of low temperature plasma, a novel technology in grain processing, not only maintained the high nutritional values of basmati rice flour, but also provided a better functional properties.

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