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RESEARCH ARTICLE

Effectiveness of atmospheric cold plasma technology on physicochemical and functional characteristics of ST25 fragrant rice (*Oryza sativa* L.) flour

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ABSTRACT

Vietnam is one of the leading rice export countries in the world. ST25 fragrant rice (*Oryza sativa* L.) won the top prize for best rice in the world in 2019 and the second at World's Best Rice Contest 2020. Plasma has been considered as an innovative food processing technology. The aim of this study demonstrated the impact of time (4, 6, 8, 10, 12 min), power (160, 180, 200, 220, 240 W) and oxygen flow rate (0.2, 0.4, 0.6, 0.8, 1.0 ml/min) to the physicochemical and functional qualities of ST25 fragrant rice flour. Results showed that under plasma treatment time at 10 minutes, power 200 W, oxygen flow rate 0.8 ml/min, the amylose content (16.67±0.01 %), pasting temperature (83.21±0.02 °C), water absorption index (14.54±0.00 gm/gm sample), water solubility index (10.31±0.02 gm/100 gm sample), swelling power (14.96±0.00 gm/gm sample) were recorded. Under plasma treatment, surface of the ST25 fragrant rice flour became more hydrophilic to absorb more water resulting to shorter cooking time. Plasma treatment provides environmentally friendly processing of rice grain to limit pesticide abuse towards ecological farming.

Introduction

Rice (*Oryza sativa* L.) is one of the most important grown cereals and is the leading crops as the main ingredient of human nutrition (1, 2). It contains a great source of carbohydrates, proteins, vitamins and minerals (3). ST25 fragrant rice is indexed in the high-quality rice list with excellent economic value in export (4). ST25 fragrant rice is not only appreciated in nutritional quality but also highly valued in overall acceptability. It well resists to disease and highly adapt to the cultivation farm. This rice variety can be cultivated twice crops per year with higher yield than other rice varieties on the same area. In 2019, it's ranked the top prize and in 2020, the second for best rice in the world in World's Best Rice Contest.

Plasma has been discovered as an innovative approach in food processing industry. Plasma is mainly consisted of photons, ions, free electrons and atoms generated from corona discharge or dielectric barrier discharge (5, 7). Two types of plasma include thermal plasma and non-thermal plasma (8). The most advantages of plasma technology are safe, flexible, cheap (9). Moreover, it also releases reactive components as oxidative reagent without toxic residue (10). Plasma technology has been reported to be effective seed germination, microbial-insect-pest inactivation, enzyme inactivation and shelf-life extension of green vegetable (11, 12); surface disinfection, seed germination, vitality improving, decontamination, flour modification and pesticide mitigation on cereal grain (9, 13, 14). Plasma technology remarkably affects water permeability of grain without any damage outside (7). There were several literature mentioned to the application of plasma treatment on rice. Brown rice treated by direct current gaseous discharge plasma resulted to more water uptake (15). Plasma treatment caused a decrease in cooking duration and improvement in water uptake ratio, length expansion ratio and volume expansion ratio, water absorption of pigmented Thai rice (8). Cold plasma treatment was utilized to enhance cooking quality of basmati rice (16). Plasma treatment reduced the cooking time with soft texture firmness of parboiled rice (17, 19). Nonthermal plasma improved water absorption and reduce the cooking time in bamboo rice (20). Low pressure cold plasma greatly affected cooking and textural attributes of brown rice (21). Plasma treatment at 120 W for 20 s strongly reduced the cooking duration and the firmness of cooked rice while accelerating stickiness, elasticity, and gruel solid loss in Chinese milled rice (22). The main objective of our study was to verify the impact of different parameters of plasma treatments such as time, power and oxygen flow rate to the physicochemical and functional qualities of ST25 fragrant rice flour.

Materials and Methods

Material

ST25 fragrant rice paddy was cultivated in Soc Trang province, Vietnam. After harvesting on the field, paddy rice was passed through following steps to obtain rice grain: drying to 14% moisture content, temporary storage for 2 weeks, cleaning, hulling, milling, polishing, grading, sorting and packaging. Rice grain was finely ground by grinder to obtain rice flour. Chemical reagents such as sodium hydroxide, acetic acid, ethanol, iodine were all analytical grade (> 95 % in purity) purchased from Rainbow Trading Co. Ltd., Vietnam. Lab equipments and utensils included weight balance, centrifugator, UV-Vis spectrophotometer, viscometer, infrared drying oven, vortex mixer and test tube.

Experiments

Experiment #1

Effect of treatment time (min) to physicochemical and functional properties of ST25 fragrant rice flour. The ST25 fragrant rice flour was subjected to plasma treatment under different durations (4, 6, 8, 10, 12 min) at power 160 W and oxygen flow rate 0.2 ml/min.

Experiment #2

Effect of treatment power (W) to physicochemical and functional properties of ST25 fragrant rice flour. The ST25 fragrant rice flour was subjected to plasma treatment in 10 min under different power values (160, 180, 200, 220, 240 W) at oxygen flow rate 0.2 ml/min.

Experiment #3

Effect of treatment oxygen flow rate (L/min) to physicochemical and functional properties of ST25 fragrant rice flour. The ST25 fragrant rice flour was subjected to plasma treatment in 10 min under power 200 W at different oxygen flow rates (0.2, 0.4, 0.6, 0.8, 1.0 ml/min).

The target functions in each experiment were based on amylose content (%), water absorption index (gm/gm sample), water solubility index (gm/100 gm sample), swelling power (gm/gm sample), pasting temperature (°C).

Physicochemical Evaluation

Amylose content (%) was determined by Iodine-binding procedure (23). 0.5 gm of rice flour was blended with 5 ml of 90% ethanol and 95 ml of 1N NaOH, keeping at ambient condition for 15 min. This blend was boiled for 5 min then cooled to 30 °C. Aliquot of 500 ml of distilled water was added and mixed thoroughly. This blend was supplemented with 50 ml of acetic acid and 1 ml of iodine. The absorbance was read at 620 nm of UV-Vis spectrophotometer.

Water absorption index or WAI (gm/gm sample) was estimated as following procedure (24). 1 gm (M_1) of rice flour was mixed with 10 ml of distilled water. Mixture was boiled for 5 min then cooled to 30 °C. Supernatant of the boiled mixture was decanted by centrifugator, and then heated at 105 °C to constant weight (M_2). Flour residue (M_r) was balanced (gm).

WAI (gm/gm sample) = M_r/M_1

Swelling power or SP (gm/gm sample) = $M_r/(M_1-M_2)$

Water solubility index or WSI (gm/100 gm sample) $=100*M_2/M_1$

Pasting temperature (^{0}C) was examined by viscometer (25). 5 gm of rice flour was mixed with 95 ml of distilled water. This mixture was boiled to 90 °C, kept 4 min and cooled to 45 °C. Pasting temperature was derived from the pasting curve.

Statistical Summary

The demonstrations were prepared as 3 replicates for various sample groups. The values were expressed as mean ± standard deviation. Statistical summary was done using Statgraphics version XVI.

Results and Discussion

Effect of Treatment Time to Physicochemical and Functional Properties of ST25 Fragrant Rice Flour

Impact of treatment time of plasma technology to physicochemical and functional properties of ST25 fragrant rice flour was shown in Table 1. When increasing treatment time (4-12 min), amylose content slightly degraded (18.95±0.01 to 17.75±0.03 %), pasting temperature also went down (86.05±0.02 to 84.90±0.02 °C); meanwhile, water absorption index, water solubility index, swelling power were significantly increased (12.24±0.00 to 13.04±0.02 gm/gm sample, 8.70±0.02 to 8.96±0.01 gm/100 gm sample, 12.55±0.00 to 13.39±0.00 gm/gm sample respectively). There was not significant difference between treatment time 10 min and 12 min, the amylose content (17.89±0.02 %), pasting temperature (84.92±0.03 °C), water absorption index (13.02±0.01 gm/gm sample), water solubility index (8.95±0.00 gm/100 gm sample), swelling power (13.35±0.02 gm/gm sample) were recorded at treatment time 10 min.

Effect of Treatment Power to Physicochemical and Functional Properties of ST25 Fragrant Rice Flour

Impact of treatment power of plasma technology to physicochemical and functional properties of ST25 fragrant rice flour was was expressed in Table 2. When increasing treatment power (160-240 W), amylose content slightly degraded (17.89±0.02 to 16.79±0.02 %), pasting temperature also went down (84.92±0.03 to 83.38±0.01 °C); meanwhile, water absorption index, water solubility index, swelling power were significantly increased (13.02±0.01 to 13.73±0.00 gm/gm sample, 8.95±0.00 to 9.52±0.03 gm/100 gm sample, 13.35±0.02 to 13.99±0.01 gm/gm sample respectively). By treatment power 200 W, the amylose content (17.05±0.02 %), pasting temperature (84.01±0.01 °C), water absorption index (13.65±0.01

gm/gm sample), water solubility index (9.46±0.00 gm/ 100 gm sample) and swelling power (13.95±0.02 gm/ gm sample) were recorded.

Impact of Treatment Oxygen Flow Rate to Physicochemical and Functional Properties of ST25 Fragrant Rice Flour

Effect of treatment oxygen flow rate (L/min) to physicochemical and functional properties of ST25 fragrant rice flour was expressed in Table 3. When increasing treatment oxygen flow rate (0.2-1.0 l/min), amylose content slightly degraded (17.05±0.02 to 16.62±0.03 %), pasting temperature also went down (84.01±0.01 to 83.18±0.03 °C); meanwhile, water absorption index, water solubility index, swelling power were significantly increased (13.65±0.01 to 14.60±0.01 gm/gm sample, 9.46±0.00 to 10.36±0.00 gm/ 100 gm sample, 13.95±0.02 to 15.00±0.02 gm/gm sample respectively). There was not significant difference between treatment oxygen flow rate 0.8 ml/min and 1.0 ml/min, the amylose content (16.67±0.01 %), pasting temperature (83.21±0.02 °C), water absorption index (14.54±0.00 gm/gm sample), water solubility index (10.31±0.02 gm/100gm sample), swelling power (14.96±0.00 gm/gm sample) were recorded at treatment oxygen flow rate 0.8 ml/min. Plasma has been considered as a beneficial non-thermal emerging technique for rice grain treatment by its capability to inactivate enzyme; disinfect microbial, pest and insect without creating thermal injury and free from toxic residue (26). Plasma technology significantly improved the functional properties of wheat grain and wheat flour (7). Brown rice treated by direct current gaseous discharge plasma at power 1–3 kV, pressure 800 Pa by air in 10 min induced to more water uptake (15). Plasma treatment induced short cooking time and soft texture firmness of parboiled rice (17-19). Nonthermal plasma improved water absorption and reduce the cooking time by 12 min in bamboo rice. Final viscosity of the plasma-treated flour lowered to 306 cP (20). The water uptake of brown rice was increased from 2.2 to 2.36 gm/gm. Cooking time was reduced from 29.1 min to 21.1 min with respect to power and time by cold plasma treatment (21). Plasma treatment at 120W–20s enhanced the cooking characteristics of milled rice by inducing to shorter cooking time, rough kernel surface, higher water absorption index, weak protein network and a higher speed of starch gelatinization (22).

Table 1. Effect of treatment time (min) to physicochemical and functional properties of ST25 fragrant rice flour

Treatment time (min)	**4**	**6**	**8**	**10**	**12**
Amylose content (%)	18.95±0.01^{a}	18.66±0.03^{ab}	18.13±0.01^{ab}	17.89±0.02^{b}	17.75±0.03^{b}
Water absorption index (gm/gm sample)	12.24±0.00^{b}	12.53±0.01^{ab}	12.81±0.00^{ab}	13.02±0.01^{a}	13.04±0.02^{a}
Water solubility index (gm/100 gm sample)	8.70±0.02^{b}	8.79±0.03^{ab}	8.87±0.02^{ab}	8.95±0.00^{a}	8.96±0.01^{a}
Swelling power (gm/gm sample)	12.55±0.00^{b}	12.81±0.02^{ab}	13.07±0.03^{ab}	13.35±0.02^{a}	13.39±0.00^{a}
Pasting temperature (◦C)	86.05±0.02^{a}	85.89±0.01^{ab}	85.37±0.00^{ab}	84.92±0.03^{b}	84.90±0.02^{b}

Figures are the mean of three replications; Figures in row followed by the same letter/s are not differed significantly (α = P=0.05).

Table 2. Effect of treatment power (W) to physicochemical and functional properties of ST25 fragrant rice flour

Treatment power (W)	**160**	**180**	**200**	**220**	**240**
Amylose content (%)	17.89±0.02^{a}	17.26±0.01^{ab}	17.05±0.02^{ab}	16.83±0.03^{b}	16.79±0.02^{b}
Water absorption index (gm/gm sample)	13.02±0.01^{b}	13.26±0.03^{ab}	13.65±0.01^{a}	13.70±0.02^{a}	13.73±0.00^{a}
Water solubility index (gm/100 gm sample)	8.95±0.00^{b}	9.22±0.02^{ab}	9.46±0.00^{a}	9.49±0.01^{a}	9.52±0.03^{a}
Swelling power (gm/gm sample)	13.35±0.02^{b}	13.64±0.01^{ab}	13.95±0.02^{a}	13.98±0.03^{a}	13.99±0.01^{a}
Pasting temperature (◦C)	84.92±0.03^{a}	84.37±0.00^{ab}	84.01±0.01^{b}	83.69±0.00^{bc}	83.38±0.01^{c}

Figures are the mean of three replications; Figures in row followed by the same letter/s are not differed significantly (α = P=0.05).

Table 3. Effect of treatment oxygen flow rate (L/min) to physicochemical and functional properties of ST25 fragrant rice flour

Oxygen flow rate (L/min)	**0.2**	**0.4**	**0.6**	**0.8**	**1.0**
Amylose content (%)	17.05±0.02^{a}	17.01±0.03^{a}	16.85±0.00^{ab}	16.67±0.01^{b}	16.62±0.03^{b}
Water absorption index (gm/gm sample)	13.65±0.01^{b}	13.72±0.00^{b}	14.05±0.02^{ab}	14.54±0.00^{a}	14.60±0.01^{a}
Water solubility index (gm/100 gm sample)	9.46±0.00^{b}	9.51±0.01^{b}	9.92±0.03^{ab}	10.31±0.02^{a}	10.36±0.00^{a}
Swelling power (gm/gm sample)	13.95±0.02^{b}	13.99±0.03^{b}	14.41±0.01^{ab}	14.96±0.00^{a}	15.00±0.02^{a}
Pasting temperature (◦C)	84.01±0.01^{a}	83.99±0.02^{a}	83.65±0.03^{ab}	83.21±0.02^{b}	83.18±0.03^{b}

Figures are the mean of three replications; Figures in row followed by the same letter/s are not differed significantly (α = P=0.05).

Amylose content play an important role influencing to the overall acceptabilities of cooking, eating and pasting attributes of a rice species (27, 28). The more amylose content a shorter cooking time was needed and vice versa. Amylose content in rice from 20 to 25% was greatly preferred as moist in cooking and soft even cooling (29). High amylose content in rice resulted dry and fluffy on boiling, but hard on cooling due to the retrogradation of amylose elements (27). Amylose content was strictly correlated to elongation of rice (30). Amylose content greatly influenced to the gelatinization, pasting behavior, swelling power, crystallinity and starch digestibility (31, 32). Water absorption index was an important variable in cooking rice. Water absorption index reflected the capability of grain to absorb and hold moisture against gravity. Acceleration of water absorption index after plasma treatment could be explained by the hydrolytic depolymerisation of starch (33). Water absorption index was greatly correlated to bulk density. The higher bulk density the higher water absorption index was achieved. Disorganized cellular structure induced the more probability for water absorption in cooking. Increase of water absorption index was strongly correlated to the decrease of the pasting temperature. The pasting temperature lowered as a result of increasing treatment duration. Plasma treatment etched the outer layer of polymeric membranes inducing to accumulation in hydrophilicity (34). Water solubility index illustrated the capability of particles to dissolve with water under an excess water condition. The water absorption index and swelling power reflected the interactions between the water molecules andthe starch chains in the crystalline and amorphous parts (25). The absorption index and swelling power proved a negative correlation with the amylose content (35). Rice consisted low amylose content had low pasting temperature (36). Rice grain had low pasting temperature resulted to shorter time of cooking as well as low energy consumption.

Conclusion

The present study revealed that technical variables of plasma treatment had significant impact to the physicochemical and functional attributes of ST25 fragrant rice flour, particularly degradation of amylose content and pasting temperature but improvement of water absorption index, water solubility index, swelling power. Plasma technology is effective to enhance quality characteristics of ST25 rice grain. The treated rice grain would become alternative raw material as gluten free ingredient for further processing different kinds of food with low glycemic index.

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Authors' contributions

Nguyen Phuoc Minh arranged the experiments and also wrote the manuscript.

Conflict of interests

The author strongly confirms that this research was conducted with no conflict of interest.

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