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Evaluation of Water Absorption Behaviour and Rehydration Kinetics of Instant Rice as Influenced by Freezing Pretreatment

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Abstract: Instant rice was prepared using popular Indian rice varieties by freeze thaw dehydration method. The effect of variable freezing rate (slow and quick) and freezing temperature (-20, -50 and - 80°C) on water absorption behaviour and rehydration kinetics were evaluated. The results revealed that both freezing temperature and freezing rate had a direct impact on the absorption of water and rehydration attributes of the instant rice. Pretreatment at -20°C (slow freezing) of instant rice led to formation of larger pore size, which in turn increased the water diffusion inside the dehydrated instant rice. Lower initial rehydration value was observed for medium grained varieties (*Sona Masuri* and *Jeerakasala*) as compared to long slender grained varieties (PB1509, PB1121, PS17, PB-PB1509). *The Jeerakasala* variety pretreated at – 20 °C freezing temperature exhibited the highest water absorption rate as 171.45 g/min/100 g of dry matter during rehydration. Based on the desirable water absorption, rehydration, colour and organoleptic properties, slow freezing at -20°C emerged as the preferred freezing method for all rice varieties. Based on estimates of R^2, Chi square and RSME, both empirical models (Peleg model as well as Singh and Kulshrestha model) used in predicting the moisture uptake during the rehydration process were found suitable.

Keywords: Freezing, Instant rice, Organoleptic evaluation, Rehydration kinetics, Water absorption.

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1. Introduction

Rice *(Oryza sativa* L.) is an extensively consumed food crop around the globe, and essentially requires cooking for consumption. In our country, *indica* subspecies of *O. sativa*, with intermediate amylose content, is widely grown and consumed. The preference for rice kernel shape or size differed from one consumer group to another (Cuevas *et al*., 2016) or from one region to another. Genetic makeup of the rice variety and growing environmental conditions are mainly responsible for differences in the composition and cooking characteristics of rice grain. Higher amounts of amylose, protein and fat contents obstruct water absorption and increase the cooking time. Amylose content influences the starch characteristics, eating and cooking qualities of rice (Hu *et al*., 2021). Moreover, chalky grains enhance the ratio of water absorption and capacity, and reduce the cohesiveness and hardness of cooked grains. The physical and the chemical properties of different rice varieties influence the processing as well as the quality of the milled rice (Sharma *et a*l., 2024). Pre-milling treatments such as parboiling affects the physico- chemical characteristics of rice resulting in variation in cooking and organoleptic properties of rice (Kale *et al*., 2015).

Presently, the changing dynamics of social life, the increasing participation of women in diverse career paths, and the growing emphasis on convenience together have generated a huge demand for fast and easily prepared food choices. Due to the swiftness of preparation, coupled with its versatility in accommodating both sweet and savoury preferences through the addition of various seasonings, easily prepared food emerged out as a suitable option for lightweight military rations and emergency sustenance (Bui *et a*l., 2018, Sharma *et al*., 2024). Besides, military rations predominantly consisted of ready-to-eat or quickly prepared instant/ convenience foods which armed personnel can quickly heat or rehydrate with boiling water (Semwal *et al*., 2001; Sharma *et al*., 2022). Rice being the staple food for a significant global population, the prospect of instant rice, which takes substantially less time in cooking as compared to conventional cooking of the fresh rice, holds considerable promise. However, its success hinges on its ability to meet consumer expectations in terms of both texture and flavour.

Various unit operations like soaking, pretreatments (application of salts, freezing, etc.), boiling, drying, etc. are required for the making instant rice, which affects instant rice quality. (Agrawal and co-workers, 2019; Sharma *et al*., 2022 and 2024). Freezing as a pretreatment has shown potential for further improvement in the quality characteristics of the final product. In fruits and vegetables, use of freezing pretreatment has been quite a popular method. Some researchers have suggested the use of freezing for preparation of quick cooking rice (Sripinyowanich and Noomhorm, 2011; Sasmitaloka and co-workers 2019; Sharma *et al*., 2022). Ice crystal formation during freezing led to collapsing of starch colloidal structure and consequently, resulted in porous structure (Sripinyowanich and Noomhorm, 2011). After freezing, it is important to dry cooked rice to reduce moisture to a safer level, so that it develops a desired level of porosity to have good rehydration capacity.

Colour and rehydration capability are two important considerations for consumers, as they often seek rice products with a pristine white colour and a rapid rehydration rate. The ability to rehydrate effectively is closely tied to the structural composition of the food. Changes in food structure can be attributed to either material shrinkage resulting from water loss or due to the penetration of gas resulting in expansion (Joardder *et al*., 2017).

Prior knowledge about kinetics of food rehydration plays a vital role in both designing of equipment and optimizing rehydration processes. It helps to understand the speed at which water is being absorbed and how it responds to variations in processing, allowing for the prediction of saturation time. Rehydration data also yield valuable insights into the mechanism governing water transport, aiding in the determination of the coefficient of water diffusion within products (Demiray and Tulek, 2017).

Present study is in continuation of our earlier study wherein we have evaluated different rice varieties for their suitability for development of instant rice, and the influence of freezing pretreatment on the instant rice quality (Sharma *et al*., 2022). This study aims to further establish water absorption behaviour and rehydration kinetics based on two empirical models, Singh and Kulshrestha Model (1987) and Peleg model (1988). The influence of freezing pretreatment on rehydration kinetics using empirical models on instant rice developed from various Indian rice varieties has not been studied so far. Hence, this investigation was undertaken to assess the impact of freezing as a pretreatment on rehydration kinetics and water absorption performance of instant rice prepared from a set of Indian rice cultivars.

2. Materials and Methods

Grains of six (*basmati* and non-*basmati*) rice varieties viz., Pusa Basmati 1509 (PB1509), Pusa Basmati 1121 (PB1121), Pant Sugandh 17 (PS17), *Sona Masuri* (SM), *Jeerakasala* (JR), and parboiled PB1509 (PB- PB1509) were acted as the experimental materials for this investigation. Basmati varieties PB1509 and PB1121 were procured from Indian Agricultural Research Institute (IARI), New Delhi, while PS17 was procured from Govind Ballabh Pant University of Agriculture and Technology (GBPUAT), Pantnagar, Uttarakhand. SM and JR were procured from farmers of Karnataka and Kerala, respectively. The rice samples of these varieties with varied quality characteristics were evaluated for water absorption behaviour and rehydration kinetics to examine their suitability for making instant rice with better rehydration properties.

2.1. *Instant Rice Preparation*

Instant rice from different varieties was prepared by freeze thaw dehydration method as explained by Sharma *et al.* (2022)(2024). The rice samples of each variety were washed thoroughly to remove dust particles. One kg of cleaned and washed rice samples of each variety was cooked in a pan. The rice to water ratio was maintained as 1:2 for long grained varieties (PB1509, PB1121 and PS17), and 1:3 for JR, SM and PB-PB1509. The cooked rice samples were followed by washing for elimination of extra starch with running water. The cooked rice samples were strained and excess surface moisture was removed.

Afterwards, the cooked rice samples were frozen using air blast cooling in a blast freezer at three freezing temperatures (-20°C, -50°C, -80°C). The model of blast freezer used is Model 15LU2-300 of M/s Hull Corporation Hatboro, USA. The instant rice samples that were frozen at -20 °C exhibited a slow freezing rate while samples frozen at -50°C and -80°C exhibited a quick freezing rate.

Model 30 D of Centrifugal fluidized bed dryer of ChemecEng, Mumbai, India was used at a temperature of 70°C to dry the frozen cooked rice till the moisture content reached at 5 %. Impact of freezing pretreatment conditions had been analysed on quality characteristics of instant rice on a set of rice varieties understudy.

2.2. *Water Absorption Behaviour*

Weight gain percentage was determined following Agrawal *et al.* (2019) with minor modification in our earlier study. The dried sample of instant rice (0.2 g) along with distilled water (4 mL) was heated in a beaker at 95°C for 10 minutes with one minute intervals. After draining excess water, the rice weight prior and after the boiling at every interval was examined with a weighing balance (M/s. Precisa, XB 220A, Precisa Instrument) which have accuracy of 0.001 g.

This data was utilized to estimate water absorption rate (WAR) as g/min/100 g of dry matter (DM) at different freezing temperatures for each variety.

2.3. *Rehydration Kinetics*

The kinetic studies during rehydration of the instant rice samples were described by employing models of Peleg (Peleg, 1988), and Singh and Kulshrestha (Singh and Kulshrestha, 1987).

Data of water uptake recorded during rehydration have been applied to Peleg's Model using following equation:

$$M = M_o + \frac{t}{k_1 + k_2 t} \qquad \text{Equation 1}$$

In this case, M represents the transient moisture content (% db), M_o represents the initial moisture content (% db). The k_1 and k_2 are the Peleg rate constant and Peleg capacity constant, respectively. The time in minutes is denoted as t.

The moisture uptake data during rehydration were also applied to Singh and Kulshrestha model using following equation:

$$\frac{m - m_o}{m_e - m_o} = \frac{kt}{kt + 1} \qquad \text{Equation 2}$$

Equation 2 is expressed in linear form as:

$$\frac{1}{m - m_o} = \frac{1}{k(m_e - m_o)t} + \frac{1}{m_e - m_o} \qquad \text{Equation 3}$$

In this case, m depicts the transient moisture content (% db), m_o depicts the initial moisture content (% db), and m_e depicts the equilibrium moisture content. k and t represent rate constant and time in minutes, respectively.

2.4. *Total Colour Change (ΔE)*

Colour properties (*L**, *a**, *b**) of rice samples were estimated through Tri-stimulus Hunter Colourimeter (M/s Miniscan XE Plus, Model No. 45/O-S, Hunter Associates Laboratory, Inc. Reston, VA, USA) with D65 illuminator at an observer angle of 10°. *L**, *a** and *b** signifies lightness from black to white, redness or greenness, and yellowness or blueness, respectively. Total colour change (ΔE) was determined by employing formula given below:

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

3. Organoleptic Properties

A team of semi-trained panelists assessed the organoleptic (appearance, colour, aroma, flavour, texture and overall acceptability) quality with the help of 9-point Hedonic scale (Mridula *et al.*, 2017) using freshly cooked rice and cooked samples of freezing pretreated instant rice of respective varieties under study.

4. Results and Discussion

4.1. Water Absorption Behaviour

Water absorption during rehydration was observed to be influenced by the freezing pretreatment. The impact of freezing pretreatment on WAR in all varieties is depicted in Fig. 1. The perusal of results revealed that the WAR was highest at the freezing pretreatment of -20 °C. Highest water absorption rate (171.45 g/min/100g of DM) during rehydration was achieved by variety JR pretreated at -20 °C freezing temperature. PB1509 exhibited higher WAR (96.60 g/min/100g of DM) as compared to WAR of parboiled PB1509 (87.10 g/min/100g of DM) at -20 °C freezing pretreatment, which indicated reduced water uptake in the instant rice prepared after parboiling treatment of *basmati* variety. During rehydration of instant rice samples, the quantity of total moisture or water absorbed escalated as the rehydration time rose; quick absorption rate observed for initial few minutes which gradually decreased afterwards. Sharma et al. (2024) also reported a similar pattern of increased uptake of water in the beginning of the rehydration. The pattern of water absorption rate curves (Fig. 1) for all varieties were similar. Similarly, characteristic curves for absorption of water of food materials during the rehydration were also similar irrespective of method of freezing pretreatment. Due to the porosity water absorption is probably adsorption rate controlled instead of being diffusion controlled (Rhim *et al.*, 2011).

Rehydration is a complex process with multi- faceted mechanisms involved. The primary mechanisms for rehydration observed at surface was convection and inside the open pores, capillary imbibition, internal diffusion and relaxation of the solid matrix. The capillaries and cavities neighbouring to the surface get filled with water and would yield faster saturation on the surface thereby restricting diffusion of water within the instant rice samples (Rhim *et al.*, 2011).

The rehydration ratio and rehydration time for different rice varieties varied from 1.74 to 3.48 and 3 to 6 minutes, as presented in our previous study (Sharma *et al.*, 2022). Amongst the rice varieties studied, *Jeerakasala* exhibited highest WAR and rehydration ratio, while shortest rehydration time. Greater rehydration ratio is indicative of better retaining of the primary structure in the final product (Zhao *et al.*, 2017). Therefore, for preparation of instant rice, *Jeerakasala* variety with slow freezing at -20°C and subsequently dried in a fluidized bed dryer at 70°C till 5 % moisture content were attained emerged as the best choice.

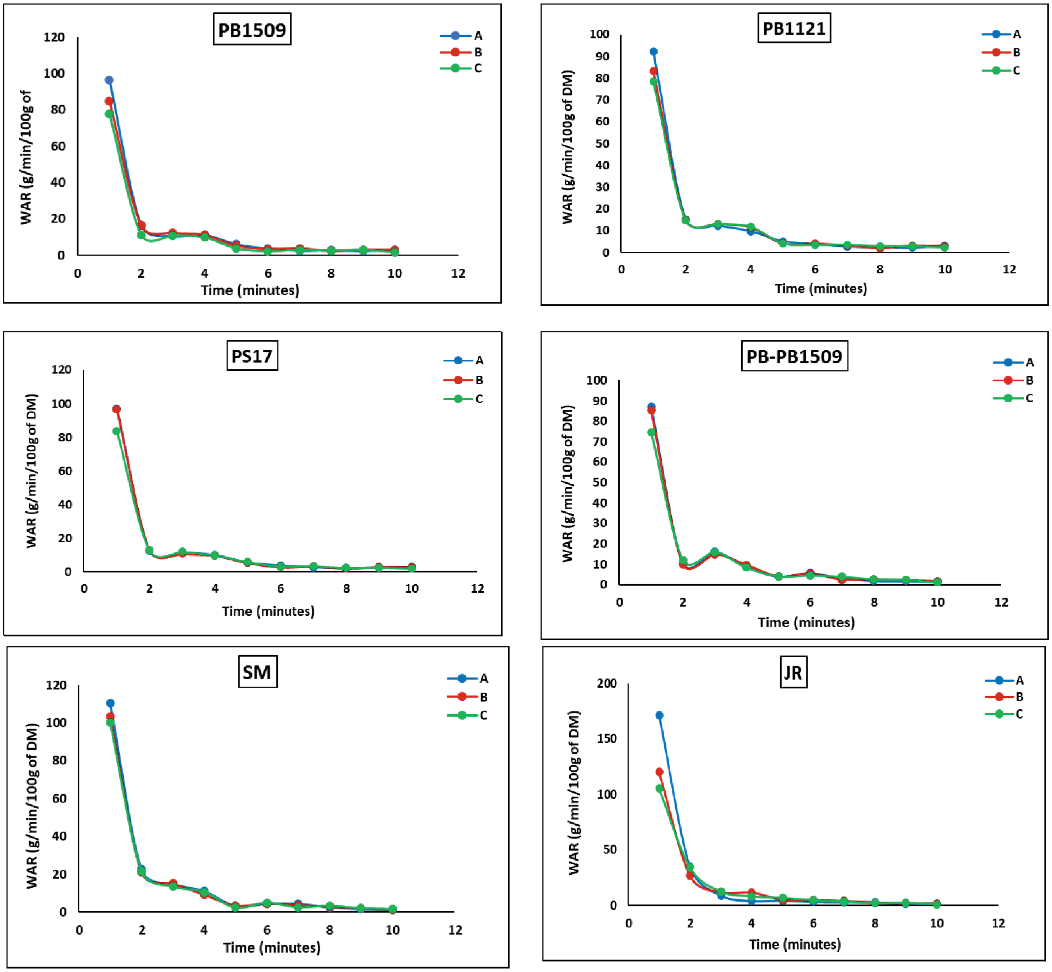


Figure 1: Water Absorption Rate (WAR) during rehydration affected by Freezing Pretreatment for different rice varieties. A: -20°C, B: -50°C, C: -80°C

4.2. Rehydration Kinetics

Peleg (1988), and Singh and Kulshrestha (1987) models examined the moisture uptake kinetics during the rehydration process. The linear regression (Table 1) was performed for calculating the model factors (k_1 and k_2 for Peleg model) and (k and m_e for Singh and Kulshrestha model).

In the Peleg model, k_1 and k_2 are Peleg rate constant and Peleg capacity constant respectively, which refer to the initial value of rehydration, and is related to the maximum water absorption capacity or the equilibrium moisture content. k_1 is related to the diffusion coefficient or mass transfer. Lower k_1 values were observed for all rice varieties at freezing pretreatment of - 20 °C which

Table 1: Parameters of rehydration kinetics of instant rice estimated by different models

		Peleg Model					Singh and Kulshrestha Model				
Variety	*Freezing Temperature (°C)*	k_1	k_2	R^2	χ^2	*RMSE*	k	m_e	R^2	χ^2	*RMSE*
PB1509	**-20**	0.011	0.001	0.989	7.544	35.230	0.290	401.18	0.968	18.711	70.431
	-50	0.012	0.001	0.990	6.021	33.392	0.235	417.79	0.972	18.976	73.357
	-80	0.013	0.001	0.994	5.125	27.527	0.194	455.60	0.980	14.388	60.878
PB1121	**-20**	0.011	0.002	0.988	7.030	26.175	0.288	385.69	0.967	18.756	70.668
	-50	0.013	0.001	0.991	5.792	31.072	0.228	417.71	0.974	17.240	67.630
	-80	0.014	0.001	0.993	5.461	28.570	0.212	417.69	0.976	18.634	70.924
PS17	**-20**	0.011	0.001	0.987	9.817	38.802	0.317	371.55	0.957	25.290	81.436
	-50	0.012	0.002	0.982	10.771	42.568	0.333	358.25	0.948	27.616	85.845
	-80	0.013	0.001	0.991	7.217	31.334	0.260	374.19	0.964	26.098	83.185
PB-PB1509	**-20**	0.012	0.002	0.992	6.460	27.932	0.262	385.71	0.975	18.251	62.790
	-50	0.013	0.001	0.992	4.618	23.108	0.264	371.44	0.970	22.330	72.203
	-80	0.014	0.001	0.994	4.618	23.108	0.208	401.04	0.978	18.200	66.764
SM	**-20**	0.008	0.001	0.994	5.024	30.702	0.301	455.69	0.983	10.605	56.332
	-50	0.009	0.001	0.993	5.035	30.373	0.294	435.92	0.983	9.215	49.769
	-80	0.009	0.002	0.992	4.511	29.510	0.296	417.74	0.981	10.913	57.205
JR	**-20**	0.004	0.002	0.985	7.969	44.722	0.685	417.74	0.980	7.534	50.362
	-50	0.007	0.001	0.995	4.040	27.136	0.338	455.59	0.986	7.811	48.036
	-80	0.008	0.001	0.997	1.553	18.123	0.263	501.02	0.995	2.297	24.652

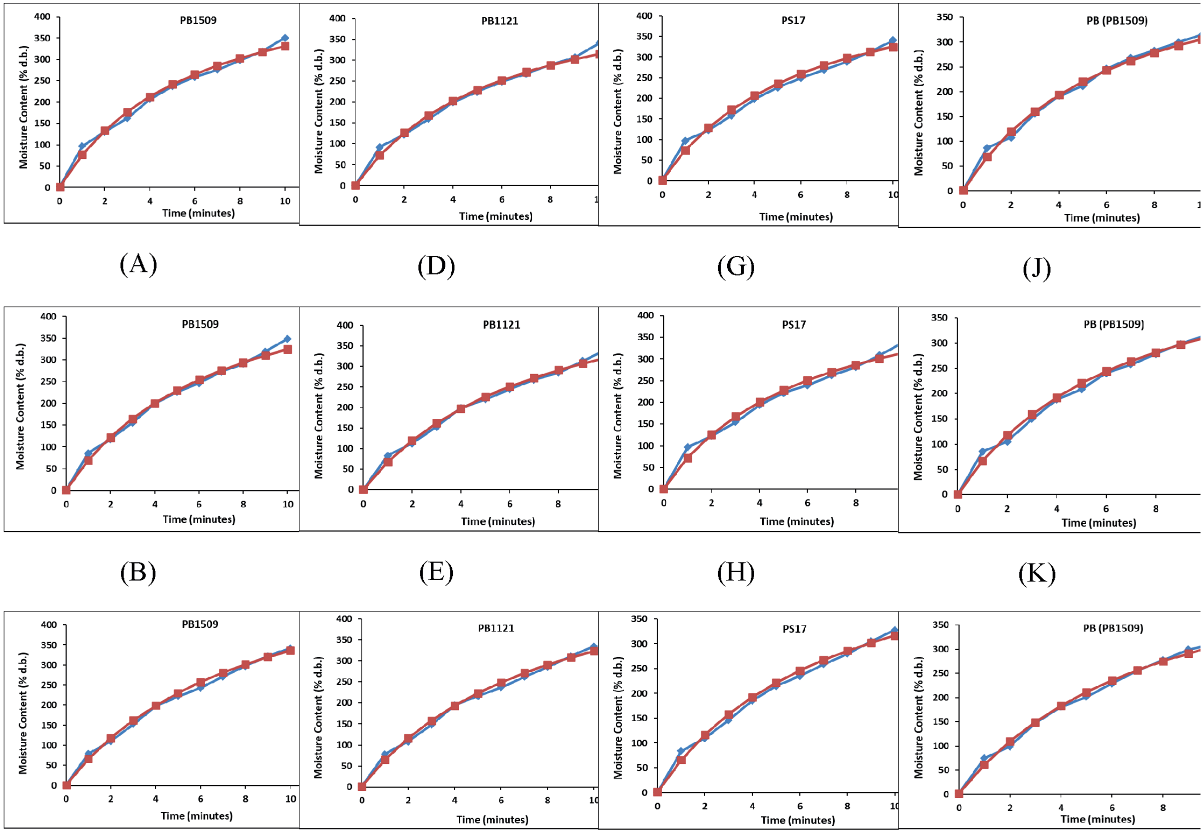
k_1: Peleg rate constant, k_2: Peleg capacity constant, *k*: Rate constant, m_e: Equilibrium moisture content, R^2: Coefficient of determination, RMSE: Root mean square error, χ^2: Chi square indicated more absorption rate at lower freezing temperature. The constant k_2 was not significantly affected by the freezing pretreatment as the values did not show much variation (Table 1). These findings were similar with the findings of Rhim et al., 2011. Amongst the varieties studied, lower k_1 value was observed for medium sized grain varieties (SM and JR) while higher k_1 values were exhibited by long slender grained (PB1509, PB1121 and PS17) varieties.

The values for k_1 and k_2 constants obtained from equation 1 were utilized to estimate the moisture content at any time. The perusal of the predicted and experimental values based on high R^2 (0.982-0.997) while low values of Chi-square ($p \leq 0.05$) revealed good agreement among them (Table 1).

Another model, viz., Singh and Kulshrestha model is effective for determining the m_e or the equilibrium moisture content, wherein extended and lengthy experiments can be avoided. The model parameters such as k (rate constant) and m_e (equilibrium moisture content) estimated from the equation were utilized to evaluate the moisture content at any time (Table 1). The predicted (expected) and experimental (observed) values exhibited a good fit which was implied through high R^2 (0.948- 0.995) while low values of Chi- square ($p \leq 0.05$) (Table 1). Similar findings have been described by Puspitowati and Driscoll (2007), Rhim and co-workers (2011) and Sharma and co-workers (2024).

During rehydration, moisture content of the rice samples increased due to water uptake. The moisture uptake during rehydration for different rice varieties (both experimental and predicted by Peleg, and Singh and Kulshrestha Models) has been depicted in Fig. 2. Higher moisture content of the rehydrated samples was observed in medium grained varieties (SM, JR) as compared to long- slender grained (PB1509, PB1121, PS17, PB-PB1509) varieties. Moisture content amongst rehydrated instant rice samples ranged from 341.85 to 350.59 % db for rice variety JR. The highest moisture content was observed for JR at -20 °C which could be attributed to more porous structure due to slow freezing, which led to higher water uptake by the rice samples during rehydration and thus, exhibited higher moisture content (Fig. 2).

The pattern for the moisture uptake curves during the rehydration of various instant rice samples were similar to the characteristic curve of moisture content during the rehydration of the instant rice, and did not exhibit influence of freezing pretreatment method, as depicted by Fig. 2. Both the models examined for evaluating kinetics during rehydration of instant rice, fitted adequately for moisture uptake during rehydration as indicated by high R^2 values, low chi- square and RMSE values (Table 1). It could be inferred that both empirical models can be successfully utilized for prediction of rehydration kinetics of instant rice.



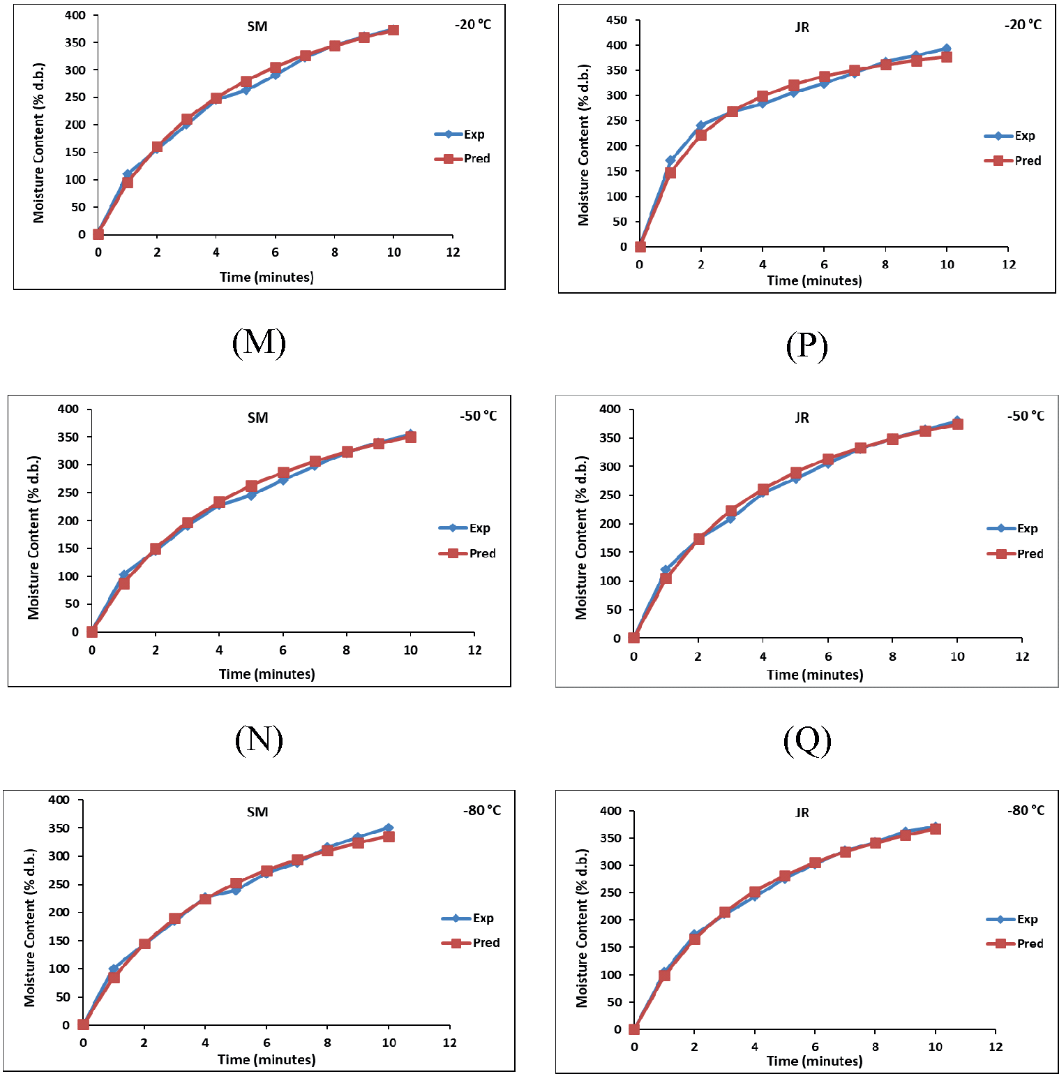
(A) (D) (G) (J)

(B) (E) (H) (K)

(C) (F) (I) (L)

PB1509 PB1121 PS17 PB (PB1509)

Figure 2a: Experimental and Predicted moisture content (% db) by Peleg Model during rehydration for long slender rice varieties at different freezing pretreatments (A-C) PB1509, (D-F) PB1121, (G-I) PS17, and (J-L) PB (PB1509



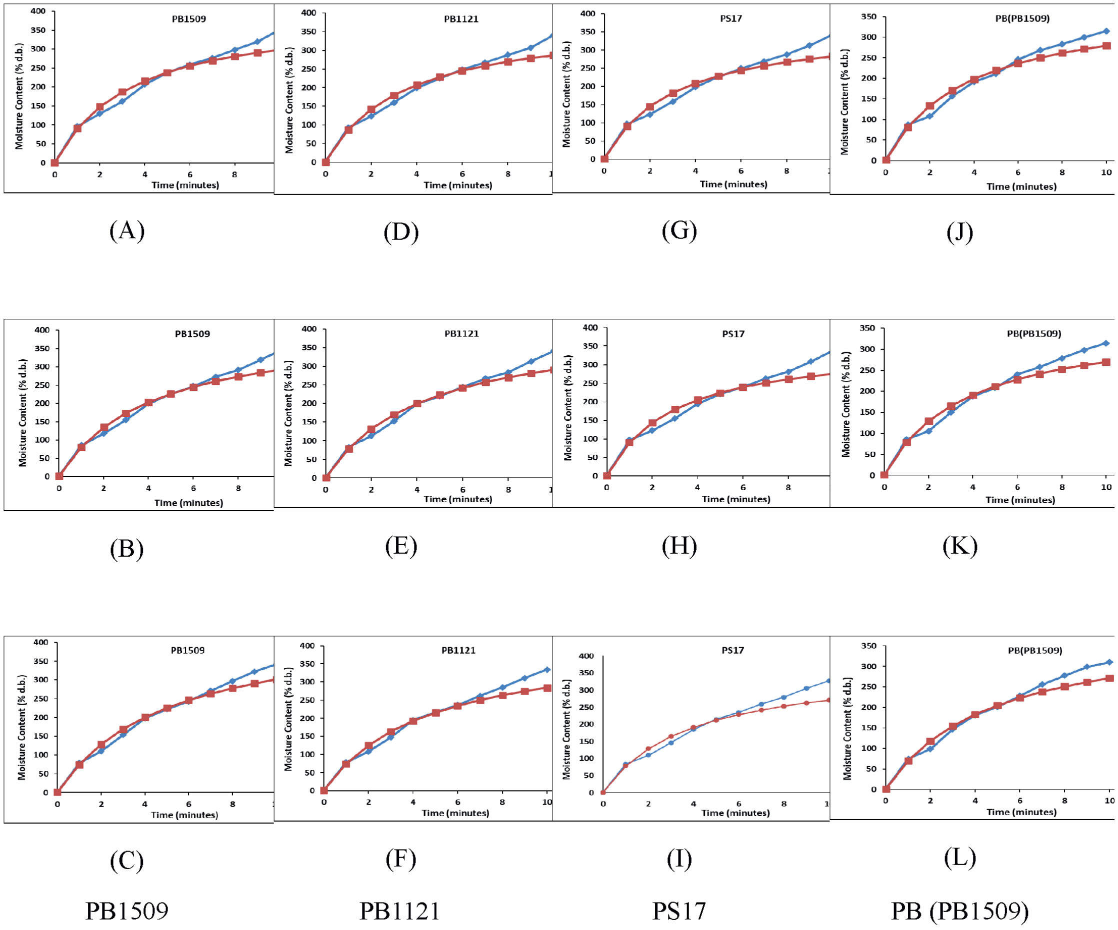
(M) (P)

(N) (Q)

(O) (R)

SM JR

Figure 2b: Experimental and Predicted moisture content (% db) by Peleg Model during rehydration for medium rice varieties at different freezing pretreatment (M-O) SM, (P-R) JR



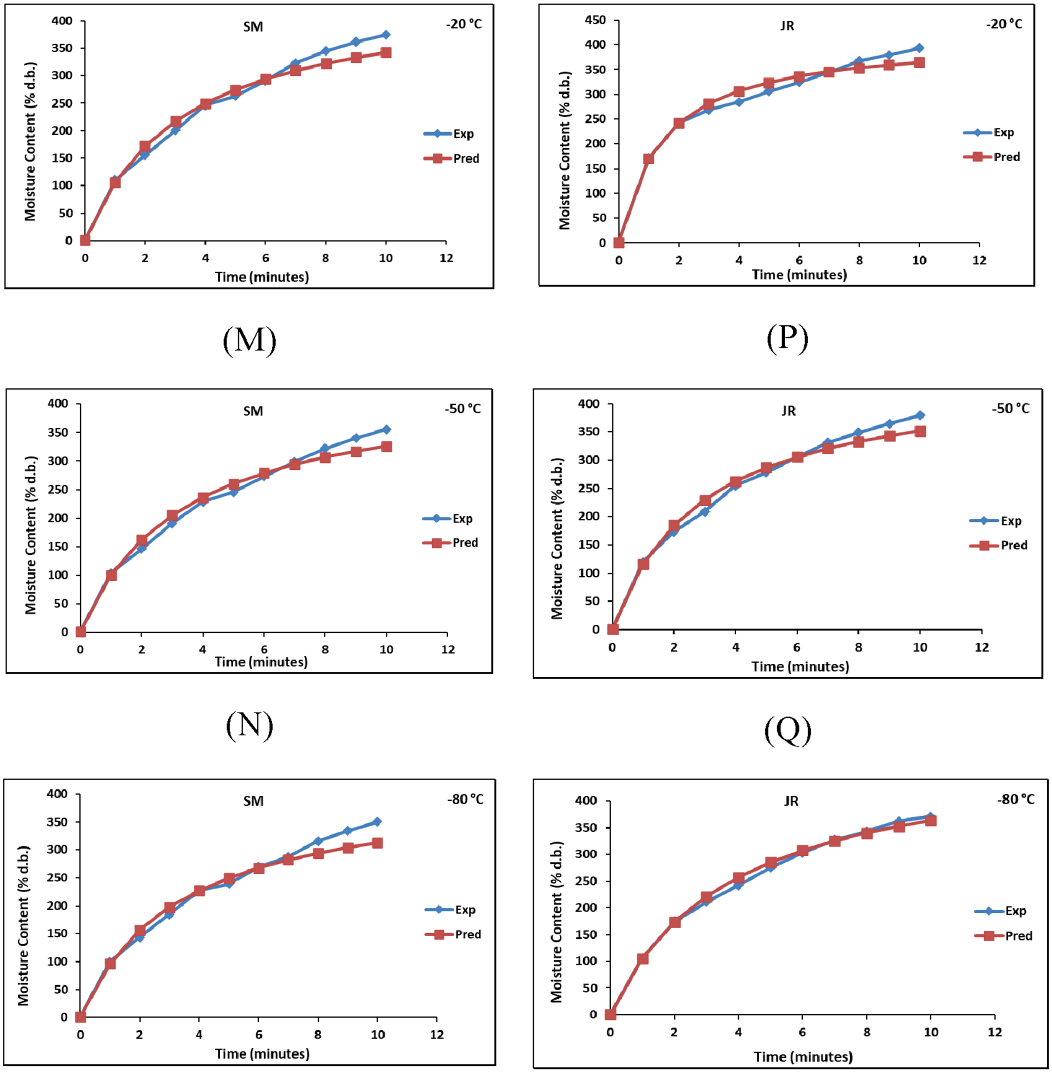
(A) (D) (G) (J)

(B) (E) (H) (K)

(C) (F) (I) (L)

PB1509 PB1121 PS17 PB (PB1509)

Figure 2c: Experimental and Predicted moisture content (% db) by Singh and Kulshrestha Model during rehydration for long slender rice varieties at different freezing pretreatments (A-C) PB1509, (D-F) PB1121, (G-I) PS17, (J-L) PB (PB1509)



(M) (P)

(N) (Q)

(O) (R)

SM JR

Figure 2d: Experimental and Predicted moisture content (% db) by Singh and Kulshrestha Model during rehydration for medium rice varieties at different freezing pretreatment (M-O) SM, (P-R) J

4.3. Total Colour Change (ΔE)

The *L** value of dried instant rice developed was comparable to the raw rice of respective varieties. Values for *L** ranged from 38.15 to 61.70, for *a** ranged from -0.95 to 1.08 and for *b** ranged from 5.25 to 12.56. Highest *L** value was observed in case of variety JR while lowest for PB-PB1509. The total colour change (ΔE) of all the samples were estimated and presented in Fig. 3. The ΔE values varied from 2.71 to 14.05 among all the treatments. The minimum value was observed in variety SM at -80 °C while the maximum value was observed for PB-PB1509 at -20 °C. In general, lower ΔE values were observed among all the varieties at a slow freezing rate pretreatment (i.e., freezing temperature of -20 °C), except for varieties PB-PB1509 and SM. The variation observed in case of these two varieties might be attributed to differences in the physico-chemical composition (Sharma *et al*., 2022). Overall, PB-PB1509 was the darkest amongst all the varieties due to the parboiling treatment, wherein the pigments present in the bran portion migrated inside the endosperm causing colour changes in parboiled rice, before preparing the instant rice. Instant rice from parboiled rice appeared to be of yellow colour and hence was not visually appealing, however,

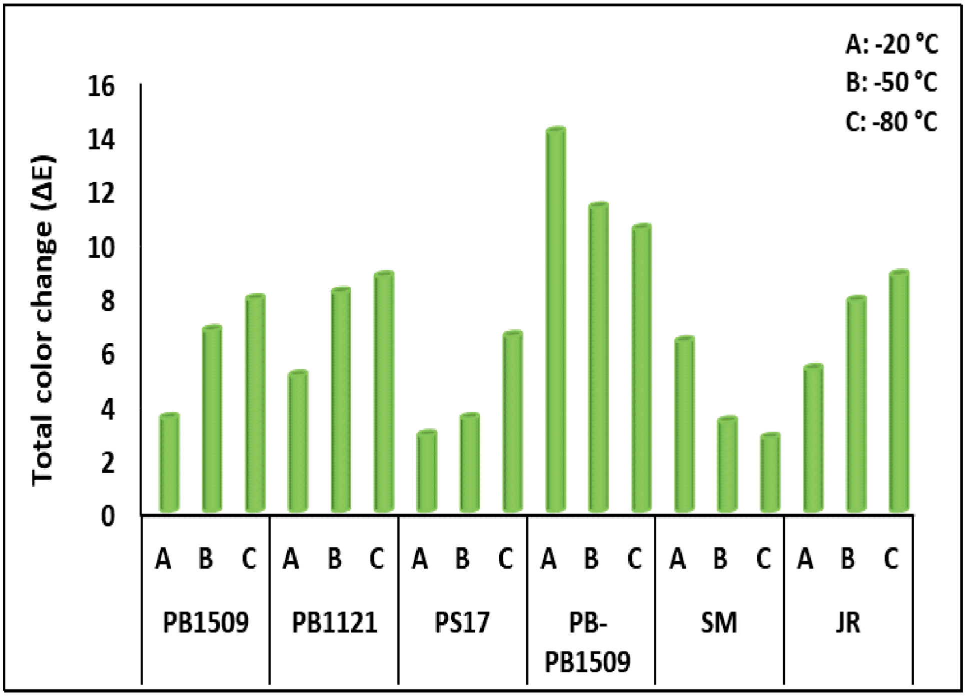


Figure 3: Total colour change (ΔE) for instant rice as affected by different freezing pretreatment. A: -20°C, B: -50°C, C: -80°C

higher nutrient retention and lower glycaemic index in parboiled rice makes it a superior choice among health-conscious individuals. Parboiled instant rice prepared by the method could also open a potential for capitalization owing to its numerous health benefits. Additionally, the total colour change observed in the other four varieties indicated some effect of enzymatic and non-enzymatic browning (Oli *et al.*, 2016).

4.4. Organoleptic Properties

The organoleptic properties of fresh cooked rice and rehydrated instant rice have been presented in Table 2a and 2b, respectively.

Table 2a: Organoleptic properties of freshly cooked rice

Variety	*Appearance*	*Aroma*	*Flavour*	*Texture*	*Overall Acceptability*
PB1509	8.50± 0.16	8.80± 0.13	8.90± 0.10	8.50±0.16	8.75± 0.13
PB1121	8.70± 0.15	8.90± 0.10	8.80± 0.13	8.70± 0.15	8.80± 0.13
PS17	7.80± 0.13	7.50± 0.16	7.00± 0.14	8.00± 0.14	7.60± 0.14
PB -PB1509	6.90± 0.18	6.80± 0.13	7.20± 0.20	7.20± 0.20	7.10 ± 0.17
SM	7.50± 0.16	6.50± 0.16	7.40± 0.16	7.40± 0.16	7.20± 0.16
JR	7.50± 0.16	8.00±0.14	8.00± 0.14	7.80± 0.13	7.80± 0.14
C.D.*	0.459	0.408	0.433	0.461	0.533
SE(m)	0.162	0.143	0.152	0.229	0.219
SE(d)	0.231	0.203	0215	0.229	0.225
CV	6.537	5.85	6.103	6.464	6.235
Mean±SE. *5% level of probability					

For freshly cooked rice, score for aroma ranged from 6.50 (SM) to 8.90 (PB1121), with an average of 7.75, while score for appearance varied from 6.90 (PB-PB1509) to 8.70 (PB1121), having an average of 7.81. The score for flavour and texture varied from 7.20 (PB-PB1509) to 8.90 (PB1509), and 7.20 (PB-PB1509) to 8.70 (PB1121), respectively. The average values of flavour and texture for freshly cooked rice was observed as 7.88 and 7.93, respectively. The overall acceptability (OAA) varied from 7.10 (PB-PB1509) to 8.80 (PB1121) with an average value of 7.86. Among rice varieties studied, PB1121 exhibited better scores for all organoleptic properties except flavour followed by PB1509. The freshly cooked rice from non- aromatic medium grained variety SM exhibited lower OAA amongst all varieties studied.

In the case of rehydrated instant rice, the score for aroma ranged from 6.40 to 8.80 having an average of 7.29. The minimum and maximum score for texture were found to be 6.60 and 8.60 respectively, with an average of 7.65.

With an average value of 7.76, flavour score varied from 6.80 to 8.80. The score for appearance ranged from 7.10 to 8.80 with average value of 7.86. The OAA varied from 6.75 to 8.75 with a general mean value of 7.62. Panellists accepted all the rehydrated samples of instant rice.

Minor differences existed in OAA scores in the samples developed using different freezing pretreatments (Table 2b). The variety PB1121 exhibited OAA score (8.75) at -20 °C followed by PB1121 (8.62) at -50 °C, PB1509 (8.55) at -20 °C and PB1509 (8.40) at -50 °C freezing pretreatment. The variety SM scored a minimum OAA score of 6.75 at -80 °C. Accumulation between grains was not observed and single kernels were distinguished in all samples. Comparable organoleptic properties of rehydrated instant rice samples and of fresh cooked rice samples were observed for all rice varieties.

Table 2b: Effect of different freezing pretreatments on organoleptic characteristics of rehydrated instant rice

Variety	*Freezing Temperature (°C)*	*Appearance*	*Aroma*	*Flavour*	*Texture*	*Overall Acceptability*
PB1509	**-20**	8.60±0.16	8.20±0.13	8.80±0.13	8.60±0.16	8.55±0.12
	-50	8.60±0.16	8.00±0.14	8.60±0.16	8.40±0.16	8.40±0.14
	-80	8.40±0.16	7.60±0.16	8.40±0.16	8.30±0.15	8.17±0.19
PB1121	**-20**	8.80±0.13	8.80±0.13	8.80±0.13	8.60±0.16	8.75±0.05
	-50	8.80±0.13	8.70±0.13	8.70±0.15	8.50±0.16	8.62±0.04
	-80	8.20±0.13	8.40±0.16	8.40±0.16	8.20±0.13	8.30±0.05
PS17	**-20**	8.20±0.13	7.20±0.13	7.80±0.13	7.80±0.13	7.75±0.20
	-50	8.10±0.23	7.10±0.18	7.80±0.13	7.70±0.15	7.67±0.21
	-80	8.00±0.14	6.80±0.13	7.60±0.16	7.60±0.16	7.50±0.25
PB-PB1509	**-20**	7.60±0.16	6.90±0.10	7.00±0.14	7.20±0.20	7.17±0.15
	-50	7.40±0.16	6.80±0.20	6.90±0.18	7.00±0.21	7.02±0.13
	-80	7.20±0.20	6.60±0.16	6.80±0.13	6.80±0.13	6.85±0.12
SM	**-20**	7.20±0.20	6.80±0.13	7.20±0.13	6.80±0.20	7.00±0.11
	-50	7.10±0.18	6.60±0.16	7.20±0.20	6.60±0.16	6.87±0.16
	-80	7.10±0.18	6.40±0.16	7.00±0.21	6.60±0.16	6.75±0.15
JR	**-20**	7.60±0.22	7.00±0.14	7.40±0.16	7.80±0.13	7.45±0.17
	-50	7.40±0.16	6.80±0.24	7.20±0.13	7.70±0.15	7.27±0.18
	-80	7.30±0.15	6.60±0.16	7.00±0.14	7.50±0.16	7.10±0.19
C.D.*		0.481	0.447	0.438	0.457	0.451
SE(m)		0.172	0.16	0.157	0.163	0.159
SE(d)		0.243	0.226	0.222	0.231	0.224
C.V.		6.929	6.939	6.437	6.758	4.160

Mean±SE. *5% level of probability

Among various varieties under study, variety PB1121 exhibited the highest score for all the organoleptic properties followed by variety PB1509, PS17, JR and PB-PB1509, while variety SM exhibited lowest score. The aromatic variety JR exhibited OAA scores in the range of 7.10 to 7.45 after different freezing pretreatments, exhibiting a good organoleptic acceptability among the panellists. The OAA score of rehydrated instant rice with freezing pretreatment and that of freshly cooked rice were found to be similar.

Among freezing pretreatments, freezing at -20°C (slow freezing) exhibited the highest scores for all the organoleptic properties and OAA across the rice varieties. The comparison of organoleptic properties at freezing temperature of -20°C (slow freezing) and freshly cooked rice did not exhibit any appreciable differences. It can therefore be inferred that there are no remarkable differences in freshly cooked and freezing pretreated instant rice for organoleptic properties. Earlier researchers (Rewthong *et al*., 2011; Sharma *et al*., 2022) also observed similar texture and flavour among the samples pretreated at – 20 °C and freshly cooked rice. The freezing pretreatment facilitated the growth of large crystals of ice, which resulted in greater size of pores after the drying process, and produced grains with softer and spongier texture after rehydration (Sharma *et al*., 2022).

5. Conclusion

The results inferred that both freezing temperature and freezing rate had a direct impact on the absorption of water and rehydration attributes of instant rice. Instant rice developed from medium grained varieties (SM, JR) exhibited higher water absorption rate and maximum amount of water absorbed in comparison to instant rice prepared from long- slender grained rice varieties (PB1509, PB1121, PS17 and PB-PB1509). Both Peleg model as well as Singh and Kulshrestha model fitted suitably for predicting the moisture uptake during the rehydration process of instant rice. The ΔE or total colour change varied from 2.71 to 14.05 for instant rice samples, and varied among different freezing pretreatments and varieties studied. Even though basmati varieties PB1121 and PB1509 exhibited slightly higher OAA scores as compared to aromatic variety *Jeerakasala*, higher water absorption resulting in rapid rehydration has made this variety a preferable choice for development of instant rice. Thus, among the freezing treatments, slow freezing at a temperature of -20 °C, while among the rice varieties, *Jeerakasala* emerged as preferred choices for getting the desirable results.

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