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Impact of Physico-chemical Variation in Different Rice Cultivars and Freezing Pretreatment for Retaining better Rehydration Characteristics of Instant Rice

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Abstract: Instant rice is well-suited for ready-to-use applications as low-moisture, light- weight military ration and emergency food for our Armed Forces, offering longer shelf life with rapid rehydration characteristics. This study demonstrated the effect of rice cultivars differing in physico- chemical properties and different freezing pretreatments on the quality of instant rice. Raw rice was cooked and spread on trays, kept in blast freezer at -20, -50 and -80°C followed by immediate drying (fluidized bed drier, 70°C, 5% m.c.) to prepare instant rice. Freezing temperature and rate, inversely related to shrinkage in instant rice, influenced the internal porous structure, and found to have a direct impact on density, texture and rehydration characteristics. Slow freezing at -20°C retained better quality attributes of instant rice. Raw long grain (PB1509, PB1121 and PS17) and parboiled PB1509 rice showed more (5-6 min), while medium and short grains (*Sona Masuri*, *Jeerakasala*) showed lesser (3-4.5 min) rehydration time by mere addition of hot water. Short- grained aromatic cultivar *Jeerakasala* exhibited comparable water absorption, kernel elongation and palatability with *basmati* rice, however, had least rehydration time (3 min) and, thus, emerged as best choice for various instant rice preparations such as instant *pulav*, *biryani*, *kheer*, etc.

Keywords: Freezing, Instant rice, Porosity, Rehydration, Water absorption.

INTRODUCTION

Globally rice (*Oryza sativa* L.) is a main staple food crop and is largely consumed in cooked form. India is the second largest producer of rice, after China, with a production and productivity level of 118.73 million tones and 2705 kg/ha during 2019-20, respectively [GOI, 2020]. Being rich in carbohydrates, it contributes about 60 to 70% of the energy needs, both as a staple as well as convenience food. With the changing trend in social life style, increasing involvement of women in various jobs, increasing convenience, there is growing need for quick and easily prepared food options. Rapid and easy preparation, besides its adaptability for sweet as well as savory palate by mixing of various condiments, makes it a suitable choice for light- weight military rations and emergency foods [Bui *et al.* 2018]. Additionally, rations for Armed Forces majorly comprise of ready-to-eat or instant convenience food products that the troops can prepare by warming or addition of hot water [Semwal *et al.* 2001]. As rice serves as main food in larger part of the world, instant rice, which takes much lesser time to cook in comparison to cooking the rice in conventional way, can play a significant role provided that, it satisfactorily meets the consumers expectation in terms of texture and taste.

Instant rice products are prepared by first hydrating and/ or precooking raw rice to gelatinize the starch; desired moisture content is achieved by then drying the treated rice. Hence, different unit operations are involved in

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the production of instant rice such as soaking, pre-treatment, boiling, and drying. These operations have been found to affect flavor, color, and textural properties of instant rice [Chen *et al.* 2014, Agrawal *et al.* 2019]. Moreover, freezing technique as a pretreatment has shown potential for further improvement in the quality characteristics of final product. Freezing, as a treatment, prior to drying has been widely followed in fruit and vegetables. Few researchers (Narkrugsa and Thunyawanith, 2005) have suggested the importance of freezing for quick cooking rice. During freezing, ice crystal formation occurs which result in breakdown of colloidal starch structure, and thus, leads to setting of porous structure (Sripinyowarich and Noomhorm 2011). After the freezing process, it is important to dry cooked rice samples to safe moisture content for it to develop a desired porous structure, which will give good rehydration capacity. Fluidized bed drying is considered the most suitable form of drying for particulates (Mujumdar 2004).

Popular rice cultivars in India are generally *indica* subspecies with long- grain and intermediate amylose content, which appease the preference of non- sticky cooked rice by the consumers. The preference for rice kernel shape or size differs from one consumer group to another (Khush *et al.* 1978). Genetic and environmental parameters are main factors for differences in chemical composition and cooking properties of rice grain. Higher amount of amylose, protein and fat hinder water absorption and increase the cooking time. Amylose content influences the starch characteristics as well as the cooking and eating qualities of rice (Juliano 1972, 1979, 1985). Moreover, chalky grains increase water absorption ratio and capacity, thereby reducing the hardness and cohesion of cooked grains. Functional properties reflect the complex interactions amongst the chemical composition, structure, molecular conformation and the physico- chemical characteristics of the food components, and their influence on the product quality characteristics. Parboiling process alters the physico-chemical properties of rice resulting into variation in cooking and organoleptic properties of rice (Bui *et al.* 2018).

One of important requirement of instant rice is that it should be capable of rehydrating quickly either by heating in hot water or by mere addition of hot water. The properties of instant rice are affected by physical as well as chemical changes; both these changes are responsible for rehydration characteristics, structural properties and organoleptic characteristics (Agrawal *et al.* 2019). The structure of instant rice and its rehydration characteristics are highly influenced by the physico- chemical properties and freezing pretreatments of rice. Limited studies have taken into account the influence of different rice types (Bui *et al.* 2018, Durgrao *et al.* 2017) and variable freezing pretreatment conditions (Sasmitaloka *et al.* 2019) on the quality attributes of instant rice. Therefore, the aim of present study was to study the comparative effect of physico-chemical variation in different rice cultivars and variable freezing pretreatment conditions for retaining better rehydration characteristics of instant rice. The final optimal processing treatment and suitable rice type based on rehydration characteristics has been indicated.

MATERIALS AND METHODS

Materials

Six different rice cultivars, viz., two *basmati* cultivars (PB1509, PB1121), long grain non-*basmati* cultivar Pant Sugandh 17 (PS17), *Sona Masuri* (SM), *Jeerakasala* (JR), and parboiled basmati cultivar PB1509 coded as PB (PB1509) with variable quality characteristics were analyzed for their physico- chemical properties to assess their suitability for development of instant rice with better rehydration characteristics.

METHODS

Physicochemical Properties of Raw Rice

Axial dimensions such as grain length (GL), grain breadth (GB) and grain thickness (GT) of all the cultivars under study were measured using vernier caliper having a least count of 0.001 mm (Model: PR26, Aerospace). Bulk density (BD) was calculated by method of Wani et al (2013). Tapped density (TD), true density (TrD) and porosity (P) were calculated by the method of Meera et al (2019). For measuring thousand kernel weight (TKW), counted 1000 rice grains were randomly selected and weighed using a precision electronic balance having an accuracy of 0.001 g (M/s Precisa, XB 220A, Precisa Instrument) (Varnamkhasti *et al.* 2018)).

Color of raw rice kernels were measured using Tri- stimulus Hunter Colorimeter (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° and color coordinates L^*, a^*, b^* were determined. Whiteness (WI) was calculated as mentioned below:

$$WI= 100- [(100-L^*)^2+ a^{*2} + b^{*2}]^{1/2}$$

The proximate composition (moisture, protein, fat, ash and fiber) of the rice samples were estimated by standard AOAC protocols (AOAC 2000). The carbohydrate content was estimated by difference method.

Total starch content (TSC) was estimated by Anthrone reagent method (Sadasivam and Manikarn 1992). Amylose content (AC) was determined by colorimetric method [19]. Amylopectin content was determined by subtracting the amylose content from total starch content. Ratio of amylose to amylopectin (Am/Ap) was calculated by dividing the respective values of amylose content by amylopectin content for each cultivar.

Functional properties of rice such as water absorption index (WAI), water solubility index (WSI), oil absorption index (OAI), swelling capacity (SC), foaming capacity (FC), and foaming stability (FS) were measured.

WAI and WSI were estimated by the method described by Kadan et al (2008). In 10mL of distilled water, 1g of rice flour was added, and vortexed for one minute. Afterwards, the suspension was heated in a water bath at 30°C for 30 minutes, followed by centrifugation at 3000 rpm for 10 minutes. The supernatant was collected in a petri plate and dried. The weight of the sediment was noted. WAI and WSI were calculated using following formulas:

WAI (g/g) = weight of sediment/ dry weight of flour

WSI (%) = (weight of dried supernatant/ dry weight of flour) × 100

OAI was estimated by the method described by Olu et al (2012). In 1 g of rice flour, 10 mL of soybean oil was added. It was then centrifuged at 4000 rpm for 20 minutes. The oil was decanted and the weight of the sediment was recorded. OAI was calculated by the formula described below:

OAI (g/g) = weight of oil absorbed/ weight of dry flour sample

SC was analyzed as per the method of Okaka and Potter (1977). A 100 mL graduated stoppered cylinder was filled with rice flour sample up to the mark of 10 mL. Distilled water was added until the total volume reached 50mL.The top of the cylinder was covered tightly with the lid and the sample was mixed by inverting the cylinder. After two minutes, the suspension was again inverted and was left to stand for another eight minutes. The volume occupied was then noted.

Foaming properties (FC and FS) were estimated by the method described by Seena and Sridhar (2005). A 50 mL distilled water was added to rice flour sample (2 g), followed by blending for three minutes in a mixer at 7000 rpm. Subsequently, it was poured in a graduated cylinder. The volume before and after whipping were recorded for calculating FC. The volume of foam that remained after 1h at room temperature was recorded for calculating foam stability as percentage of initial foam volume.

Preparation of Instant Rice

The rice samples were washed thoroughly to remove dust particles. Then, 1 kg rice samples were cooked keeping rice to water ratio of 1:2 for long grain cultivars (PB1509, PB1121, PS17), and 1:3 for JR, SM and PB (PB1509) rice cultivars.

The cooked rice was washed four times with running water for removal of excess starch. The cooked rice was strained and was left to dry out surface moisture.

After cooking rice to attain complete gelatinization, cooked rice is frozen using air blast cooling in a blast freezer (Model 15LU2-300, M/s Hull Corporation Hatboro, USA). Cooked rice was frozen at three different freezing temperatures of -20°C, -50°C and -80°C, which caused variable freezing rate (slow and quick freezing).

After freezing, the frozen cooked rice was dried using the high velocity air stream (temperature: 70°C up to moisture level about 5%) of fluidized bed dryer (Model 30 D, ChemecEng, Mumbai, India), that swiftly takes away moisture from the surface and avert sticking of kernels. Fluidized bed drying causes puffing on volume expansion which leads to enhanced porosity. The individual frozen cooked rice kernels moved separately from each other through the flowing hot air of fluidized bed drier, and thereby effective absorption of heat by the kernels.

Impact of freezing pretreatment conditions were analyzed on quality characteristics of instant rice prepared from different rice cultivars.

Quality Evaluation of Instant Rice

Water Activity

The water activity of instant rice samples was measured using a water activity meter (Model, Hygrolab 3; Make, Rotronic, Germany).

Bulk density

Instant rice was put in a 100 mL cylinder and tapped 25-30 times, and then weight of instant rice was measured. Density was calculated as weight by volume of instant rice.

Degree of damaged grains

A representative sample of instant rice (approximately 10 g) was drawn for each rice cultivar and manually sorted for whole grains, broken grains and clumped grains. Each category was separately weighed. Total damaged grains were calculated by addition of both broken and clumped grains and percent damaged grains were calculated.

Color Properties

Color values of dried instant rice kernels were measured using the same methodology as used for raw rice.

Volume expansion

Volume of instant rice before and after rehydration were measured and the volume expansion % (VE%) were calculated using following formula as suggested by Prasert & Suwannaporn (2009):

Volume expansion % = [(Volume of rehydrated rice- volume of rice before rehydration) / volume of rice before rehydration] × 100

REHYDRATION CHARACTERISTICS

Weight gain percentage

Weight gain percentage was estimated by the method described by Agrawal et al (2019) with slight modification. The dried instant rice sample (0.2 g) was put in 10 mL of heated water at 95°C in a beaker for a period of 1 to 10 minutes. The excess water was drained. The weight of rice before and after heating at each interval was determined using precision electronic weighing balance. Weight gain percentage was calculated by dividing the gain in weight at each interval by initial dried rice weight, and multiplied by 100.

Rehydration ratio and rehydration time Approximately 100 g of instant rice was treated with 500 mL hot water (90°C) in a stainless-steel vessel, covered and set aside until they attained the consistency of cooked rice. The excess water was drained. Rehydration ratio was calculated as the ratio of weight of rehydrated sample to the weight of dehydrated sample. Rehydration time was estimated as the time required to attain the consistency of cooked rice (Semwal *et al.* 2001).

Statistical Analysis

The mean data of three replications for each character were reported. The replicated data was statistically analyzed for analysis of variance (ANOVA), using OPSTAT software, and Pearson correlation (r) was calculated for establishing relation between instant rice quality parameters.

RESULT AND DISCUSSION

Physico- chemical properties of different raw rice cultivars

Physico- chemical properties of rice cultivars affect the processing, handling, grading, marketability and end- product quality of milled rice. The different physico- chemical properties of rice cultivars under study are presented in Table 1. The GL ranged from 5.53 mm for JR to

8.40 mm for PB 1509, while GB ranged from 1.70 mm for PB 1509 to 2.50 mm for PB (PB1509). The minimum value for GT (1.58 mm) was observed in raw PB1509 and JR while maximum value (2.19 mm) was found in PB (PB1509). The cultivar JR exhibited highest BD (874.43 kg/m^3), TD (928.32 kg/m^3), TrD (1468.29 kg/m^3) and porosity (36.77%), while PB (PB1509) exhibited lowest values for these characteristics. In general, longer grains depicted lower density characteristics. The results are consistent with the earlier finding of Singh *et al.* 2005. The WI ranged from 32.92-60.42 for all the cultivars studied. Lowest WI was depicted by PB (PB1509) while highest WI was depicted by JR. Highest TKW (23.98 g) and grain hardness (19.75 N) were found in parboiled PB1509, while lowest TKW (15.92 g) and grain hardness (8.86 N) were exhibited by rice cultivar JR. Among functional properties, cultivar JR exhibited highest WAI (1.92%) and WSI (5.80%) while PB (PB1509) exhibited highest OAC. The non- aromatic cultivars PS17 and SM exhibited highest and lowest values for FC (1.87% and 0.92%), FS (0.97% and 0.68%) and SI (16.4% and 12.04%), respectively.

The proximate composition of rice cultivars under study has been presented in Table 2. The moisture, protein, fat, ash, fiber and carbohydrate contents varied from 11.26 to 12.52%, 7.21 to 8.8%, 0.48 to 0.87%, 0.46 to 0.68%, 0.06 to 0.31% and 77.19 to 79.49%, respectively. PB1121 had higher moisture, protein and ash contents but found to have lower carbohydrate content. PS 17 showed highest fat content and lowest fiber and moisture contents. Rice cultivar JR had highest fiber content and lowest fat and ash contents.

JR cultivar exhibited highest TSC and AC while lowest amylose/ amylopectin ratio. PB (PB1509) depicted lowest TSC, AC and amylopectin content, but exhibited highest amylose/ amylopectin ratio. The PB (PB1509) exhibited higher ash and fiber contents and lower values for fat and protein content as compared to the raw PB1509.

The pasting properties are indicative of alteration in paste viscosities of flour suspension under a regulated heating and shearing conditions (Sharma *et al.* 2001). Pasting properties can be related with the cooking and the textural attributes of cooked rice. PV, TV, SBV, BDV, FV and PT ranged from 542- 3764 cP, 548-3082 cP, 446-2456 cP, –6-682 cP, 988- 6220 cP, and 87- 90.9°C, respectively (Table 3). PS17 and PB (PB1509), respectively, exhibited highest and lowest values for PV, TV, SBV and FV. Rice cultivar PS17 had highest value for PV, which indicated the higher ability of the starch granules to swell. High values of SBV for PS17 depicted its high tendency to retrograde. Highest BDV was observed in case of cultivar PB1509 while lowest BDV was observed in PB (PB1509). Extensive thermal breakdown of starch after the parboiling treatment lowered the pasting properties of parboiled PB1509. Highest BDV of raw PB1509 demonstrated the degree of ease with which the starch granules will break upon heating after attaining maximum swelling at peak viscosity.

Besides, the existence of wide range of variation, analysis of variance (Table 1-3) for different characters also indicated the significant differences among the rice cultivars for majority of characteristics. Thus, indicating the suitability of rice cultivars chosen for the present study.

Quality evaluation of instant rice

The established parameters of significance for good quality instant rice are white color, well separated, quick rehydration rate, comparable organoleptic properties to freshly cooked rice, lower degree of broken or damaged grains, higher volume expansion ratio and no hard core or ungelatinized center (Houston 1972, Luh 1980, 1991, Luangmalawat et al. 2008, Prasert and Suwannaporn 2009, Sripinyawanich and Noomhorm 2013). Few researchers (Durgrao *et al.* 2017, Sasmitaloka *et al.* 2019) have also highlighted the importance of physical properties of instant rice during design and selection of storage structures, and storage and processing equipment. The percentage of damaged grains in instant rice is an estimate of the quality of product, which is affected by the type and cooking properties of rice. Low degree of damaged grains with presence of distinct, whole rice kernels is also visually appealing to the consumer (Bui *et al.* 2018). Influence on color attributes of processed instant rice plays an important role in sensory acceptability of the product.

Table 1: Physico- chemical properties of different raw rice cultivars

Parameter	*PB1509*	*PB1121*	*PS17*	*PB (PB1509)*	*SM*	*JR*	*CD#*	*SE(m)*	*SE(d)*	*CV%*
GL (mm)	8.40±0.02	8.12±0.02	7.92±0.03	8.30±0.01	5.48±0.01	5.53±0.01	0.051	0.016	0.023	0.023
GB (mm)	1.70±0.02	1.82±0.01	1.76±0.01	2.50±0.03	2.24±0.01	2.20±0.01	0.049	0.016	0.022	1.330
GT (mm)	1.58±0.01	1.58±0.01	1.62±0.01	2.19±0.01	2.10±0.01	1.58±0.01	0.018	0.006	0.008	0.564
TKW (g)	23.74±0.28	22.18±0.51	19.09±0.12	23.98±0.64	16.28±0.16	15.92±0.07	1.141	0.366	0.518	3.141
BD (kg/m^3)	769.48±12.61	770.57±12.73	778.29±8.39	714.70±14.05	792.72±10.89	874.43±11.24	36.727	11.789	16.672	2.607
TD (kg/m^3)	904.26±9.54	910.59±10.36	922.82±9.31	883.92±4.13	898.26±7.23	928.32±14.16	N/A	9.617	13.600	1.834
TrD (kg/m^3)	1359.50±19.36	1382.51±7.76	1399.19±9.25	1259.12±20.83	1402.00±10.49	1468.29±13.19	44.764	44.764	20.320	1.805
Porosity (%)	33.48±0.25	34.13±0.49	34.04±0.25	29.79±1.24	35.93±0.10	36.77±0.52	1.872	0.601	0.850	3.059
Hardness (N)	6.62±0.25	7.087±0.07	8.73±0.04	19.75±0.12	10.24±2.81	8.86±0.01	3.592	1.153	1.153	10.545
*L**	58.61±0.18	56.14±0.04	56.42±0.23	37.01±0.04	55.03±0.58	61.86±0.03	0.828	0.266	0.376	0.376
*a**	-0.44±0.01	-0.73±0.01	-0.64±0.01	1.87±0.01	-1.38±0.01	-1.39±0.02	0.337	0.012	0.017	0.017
*b**	7.71±0.10	10.84±0.03	9.41±0.01	22.92±0.01	8.18±0.10	10.48±0.05	0.201	0.065	0.091	0.966
WI	57.89±0.76	54.81±0.19	55.41±0.08	32.92±0.11	54.27±0.22	60.42±0.24	1.096	0.352	0.352	1.158
WAI (%)	1.79±0.02	1.46±0.02	1.80±0.01	1.32±0.01	1.65±0.02	1.92±0.01	0.04	0.015	0.022	1.616
WSI (%)	5.50±0.21	5.20±0.02	5.60±0.03	4.80±0.01	5.30±0.01	5.80± 0.02	0.271	0.087	0.123	2.810
OAI (%)	0.81±0.02	0.85±0.02	0.80±0.01	0.88±0.01	0.86±0.01	0.78±0.01	0.041	0.013	0.019	2.739
FC (%)	1.16±0.02	1.62±0.02	1.87±0.01	1.09±0.01	0.92±0.01	1.02±0.01	0.044	0.014	0.020	1.923
FS (%)	0.82±0.02	0.94±0.02	0.97±0.02	0.79±0.01	0.68±0.02	0.76±0.01	0.047	0.015	0.021	3.162
SI (%)	15±0.58	16.2±0.14	16.4±0.02	13.11±0.06	12.04±0.02	13.06±0.01	0.762	0.245	0.346	2.963

GL: Grain length, GB: Grain breadth, GT: Grain thickness, TKW: Thousand kernel weight, BD: Bulk density, TD: Tapped Density, TrD: True Density, *L**: lightness, *a**: redness-greenness, *b**: yellowness-blueness, WI: Whiteness, WAI: Water absorption index, WSI: Water solubility index, OAI: Oil absorption index, FC: Foaming capacity, FS: Foaming stability, SI: Swelling index. # at 5% level of probability

Table 2: Proximate analysis of different raw rice cultivars

Parameter	*PB1509*	*PB1121*	*PS17*	*PB (PB1509)*	*SM*	*JR*	*CD#*	*SE(m)*	*SE(d)*	*CV%*
Moisture (%)	11.56±0.04	12.52±0.29	11.26±0.27	11.86±0.06	11.65±0.14	11.91±0.11	0.564	0.181	0.25	2.657
Protein (g)	7.9±0.06	8.8±0.07	8.61±0.06	7.21±0.02	8.15±0.19	7.79±0.02	1.526	0.490	0.693	10.004
Fat (g)	0.75±0.02	0.59±0.03	0.87±0.01	0.62±0.01	0.51±0.01	0.48±0.02	0.043	0.014	0.019	3.714
Ash (g)	0.51±0.03	0.68±0.01	0.53±0.01	0.54±0.03	0.67±0.01	0.46±0.01	0.051	0.016	0.023	5.011
Fiber (g)	0.2±0.02	0.22±0.03	0.06±0.01	0.28±0.01	0.28±0.01	0.31±0.02	0.052	0.017	0.017	12.809
Carbohydrates(g)	79.08±0.02	77.19±0.32	78.67±0.49	79.49±0.08	78.74±0.14	79.05±0.10	0.781	0.251	0.354	0.552
Starch (%)	75.59±0.08	74.24±0.21	76.11±0.41	62.29±0.47	78.22±0.38	79.12±0.40	1.098	0.353	0.499	0.822
Amylose (%)	52.29±0.28	50.59±0.40	51.99±0.30	42.24±0.05	55.94±0.41	58.93±0.42	1.056	0.339	0.479	2.638
Amylopectin (%)	23.3±0.27	23.65±0.41	24.12±0.30	20.05±0.05	22.28±0.41	20.1± 0.42	.052	0.338	0.478	2.628
Am/ Ap	0.44±0.01	0.46±0.01	0.46±0.01	0.47±0.01	0.39±0.01	0.34±0.01	0.021	0.007	0.009	2.703

Am/ Ap: Amylose to Amylopectin ratio. # at 5% level of probability

Table 3: Pasting properties of different raw rice cultivars

Cultivars	*PV (cP)*	*TV (cP)*	*SBV (cP)*	*BDV (cP)*	*FV (cP)*	*PT (°C)*
PB1509	2635±31.19	1851±13.69	1056±14.05	784±21.55	3691±60.80	90.9±0.01
PB1121	2462±23.06	2006±13.69	1637±23.46	456±22.60	4099±10.82	89.4±0.01
PS17	3764±20.50	3082±47.34	2456±21.63	682±15.70	6220±22.91	87±0.01
PB (PB1509)	542±16.29	548±11.85	446±16.65	-6±1.732	988±19.30	-
SM	2519±18.17	1680±26.39	1125±12.90	691±10.60	3962±21.57	88±0.03
JR	2622±20.55	2109±27.02	1578±12.89	558±14.42	3851±16.70	87.4±
CD#	66.786	942.641	54.344	49.993	93.938	NA
SE(m)	21.437	295.334	17.444	16.047	30.152	-
SE(d)	30.317	417.665	24.669	22.694	42.642	-
CV (%)	1.532	19.442	2.311	5.269	1.374	-

PV: Peak viscosity, TV: Trough viscosity, SBV: Setback viscosity, BDV: Breakdown viscosity, FV: Final viscosity, PT: Pasting temperature
at 5% level of probability

Impact of freezing pretreatments and rice cultivars on quality attributes of instant rice

Freezing pretreatment affect the physical and physico- chemical properties of instant rice, as the size and location of ice crystals that are formed during pre- freezing are majorly dependent on the freezing rate and temperature. The result of quality attributes of instant rice of different cultivars as affected by various freezing pretreatments have been presented in Table 4. The perusal of results revealed considerable range of variation in different characteristics.

WA value ranged from 0.42 for JR to 0.52 for PB (PB1509) and SM, which indicated that instant rice was efficiently dried for safe storage. The *L** value of dried instant rice developed was comparable to the freshly cooked samples of respective rice cultivars. *L**, *a** and *b** values varied from 38.15 to 61.7, -0.95 to 1.08 and 5.25 to 12.56, respectively (Table 4). Highest *L** values were observed in case of JR while lowest for PB (PB1509). Instant rice from parboiled rice appeared to be of yellow color and hence was not visually appealing, however, higher nutrient retention and lower glycemic index in parboiled rice makes it a superior choice among health-conscious individuals.

The percentage of damaged grain varied from 5.30 (JR) to 44.82% (PS17). In general, higher breakage and clumping was observed in instant rice prepared from long grains as compared to medium and short grains. Instant rice prepared from parboiled basmati rice showed relatively low degree of breakage as compared to raw basmati rice of the same cultivar. The long grains were more swollen and cooked softer, thus were subject to more damage during handling. Parboiling process provides harder, non- sticky texture to the rice, and thus becomes easy to handle resulting in lower damage and clumping of rice grains. Structural variation in starch among the raw and parboiled rice might be responsible for the difference in degree of damage caused. This structural variation can occur due to varying degree of gelatinization observed in parboiling process that leads to losses in starch content and influence rate of the water diffusion during subsequent cooking and rehydration processes. Further, the difference in retrogradation and ageing processes makes the parboiled rice highly resistant to disintegration during the cooking process, thus lower damage. In general, higher clumping was observed in case of instant rice from raw long grains due to more breakage, which leads to sticking of grains together. Average lowest and highest damaged grain percentage was found in instant rice samples of -20°C (15.35%) and -80°C (26.71%), respectively.

JR and PB (PB1509) had highest (695.24 kg/m^3) and lowest (486.19 kg/m^3) value for BD. Instant rice prepared from short and medium grains had higher average BD as compared to instant rice prepared from longer grains (Table 4). Highest average VE% was observed for *basmati* cultivar PB1121 (155.24%) and lowest for SM (126.15%). In general, longer grains depicted higher VE% as compared to short and medium cultivars. VE% is affected by water absorption; lower VE% was observed in JR rice cultivar even though it had higher water uptake value which could be attributed to the compactness of the grain which led to higher BD and lower VE%. Higher porosity and water absorption in a food matrix tends to result into higher VE. Food structures go through volumetric changes i.e., shrinkage on evaporation of water during dehydration process (Khalloufi and Ratti 2003). Lower the VE%, higher is the shrinkage and denser the product. BD depicted a negative but non- significant correlation with VE% (r= -0.995). The results are consistent with earlier findings of Sripinyowanich and Noomhorm 2013. Thus, maximum shrinkage and BD was observed for instant rice prepared at -80°C for all cultivars.

The weight gain percentage by different cultivars as influenced by different freezing pretreatments is shown in Fig 1 (A, B and C). The perusal of figure revealed that at the beginning, weight gain increased rapidly and then became constant. Highest weight gain % was observed for rice cultivar JR at all freezing temperatures while lowest value was observed for PB (PB1509). Parboiling decreased the water uptake rate of the rice. The voids or porous structures are created due to structural changes in cooked rice because of the freezing and drying processes.

During freezing, ice crystal formation occurs which result in breakdown of colloidal starch structure, and thus, leads to setting of porous structure (Sripinyowanich and Noomhorm 2011). In addition, these processing operations causes loosening of the protein structure in raw rice, which further enhanced the water absorption rate. Variation in dense areas, voids and cracks differs with the type of rice (Bui et al. 2018). Slow freezing rate at -20°C produced instant rice with more porosity and rapid water absorption, thus caused higher water absorption. As the granule structure becomes more open and porous, increment in the effective water diffusion takes place. Instant rice samples frozen at -20°C depicted higher weight grain % for all cultivars, which could be attributed to higher water absorption rate due to high porosity of slow frozen samples.

Slow freezing at -20°C produced higher rehydration ratio in all cultivars. Slow freezing forms large ice crystals and creates larger size pores, which leads to increase in water uptake and thus higher RR. Slow freezing at -20°C produced instant rice with lower average RT (4.76 mins). Rapid rehydration of instant rice was attributed to increase in its surface area as the volume increased (Prasert and Suwannaporn 2009). BD depicted positive and negative significant correlation with RT ($r = 1.000$, $p \leq 0.01$) and RR ($r = 0.998$, $p \leq 0.05$) respectively. Significant positive correlation of BD with RR was also observed by Prasert and Suwannaporn (Prasert and Suwannaporn 2009). Parboiled PB 1509 and JR respectively exhibited lowest (1.74) and highest (3.48) RR. Shortest RT was observed in case of JR (3 mins) at -20°C whereas parboiled PB1509 (6 mins) at -80°C took longest time to rehydrate. Higher RR results in shorter RT. JR depicted highest RR (3.48) and least RT (3 min) at -20°C among all the treatments.

Rice frozen at -20°C with slow freezing rate was visually more porous than the ones frozen at -50°C and -80°C. Quick freezing (-50°C and -80°C) produced instant rice with denser structure having less pore size, which results into harder and crisp texture. Instant rice produced with slow freezing (-20°C) had softer texture. Larger ice crystals with larger pore size produce porous and spongy texture after rehydration (Arunyanart and Charoenrein 2008). Additionally, increasing the pore size, as favored by slow freezing at -20°C, decreased the hard texture of rehydrated rice. As quick freezing promotes intensive nucleation, formation of smaller ice crystals takes place. Generally, larger crystals of ice that are formed during slow freezing leads to structural damages in the food, however, in case of instant rice products, structural damage is less important and slow freezing for longer duration offering better rehydration characteristics seems to be an optimal choice.

Impact of freezing pretreatments on instant rice as a function of rice cultivars

The mean performance of freezing pretreatments across different cultivars (Table 5) revealed that in comparison to -50°C and -80°C freezing temperature, -20°C freezing temperature exhibited desirable lower values for BD (547.62 kg/m^3), DG (15.35%), RT (4.76 mins), a^* (-0.23) and b^* (7.04) and higher desirable values for VE (143.97%), RR (3.08), L^* (55.95) and WI (55.35).

At -20°C, instant rice from all cultivars had higher RR, VE% and lower BD and RT. However, at -80°C, reverse trend was observed for these quality characteristics. This suggests that BD was affected by pore size, which in turn is affected by the freezing temperature and rate. Instant rice prepared at -20°C and longer freezing rate resulted into highly porous and less dense product. The results are consistent with the results of Sasmitaloka et al. 2019 who found increase in porosity in case of samples having lower density, which was prepared by longer freezing duration.

The results inferred that both the freezing temperature and the freezing rate had a direct impact on water absorption and rehydration characteristics of the instant rice by affecting the physico- chemical and structural properties of instant rice.

Impact of rice cultivars on instant rice as a function of the freezing pretreatment

The mean varietal performances of instant rice for different characteristics as a function of freezing condition are given in Table 6. By viewing the

Table 4: Quality attributes of instant rice of different rice cultivars as affected by freezing pretreatment

Cultivars	*BD (kg/m³)*	*VE (%)*	*WA*	*DG (%)*	*RR*	*RT (mins)*	*L**	*a**	*b**	*WI*
-20°C										
PB1509	490.00 ±4.87	152.15±0.50	0.50±0.01	22.15±2.56	3.28±0.04	5.00±0.23	55.67±0.30	-0.48±0.02	5.91±0.07	55.27±0.16
PB1121	510.32 ±11.37	155.24± 2.06	0.48±0.01	20.89±3.11	3.06±0.03	5.33±0.01	53.89±0.05	-0.69±0.02	6.35±0.04	53.44±0.25
PS17	536.22±18.82	154.82±0.95	0.53±0.012	26.08±4.17	3.06±0.03	5.00±0.17	57.82±0.09	-0.55±0.02	6.98±0.12	57.24±0.15
PB (PB1509)	486.19±6.32	37.777 ±0.74	0.52±0.012	7.38±0.76	2.76±0.04	5.95±0.11	45.82±0.12	0.86±0.02	12.02±0.10	44.49±0.13
SM	620.21±16.26	12.126±1.63	0.52±0.006	10.28±1.28	2.86±0.04	4.30±0.05	60.78±0.06	-0.76±0.01	5.72±0.14	60.35±0.16
JR	642.80± 18.23	17.148±0.99	0.46±0.006	5.30±0.57	3.48±0.05	3.00±0.01	61.70±0.13	-0.87±0.03	5.25±0.14	61.33±0.17
CD	43.027	3.950	0.026	7.657	0.118	0.267	0.458	0.059	0.342	0.512
SE(m)	13.811	1.268	0.008	2.458	0.038	0.086	0.147	0.019	0.110	0.165
SE(d)	19.532	1.793	0.012	3.476	0.054	0.121	0.208	0.027	0.155	0.220
C.V. (%)	4.366	1.526	2.855	27.738	2.135	3.151	0.455	4.655	2.698	0.701
-50°C										
PB1509	512.11±13.33	150.96±1.42	0.47±0.006	35.40± 4.27	2.88±0.05	5.15±0.03	52.01±0.10	-0.57±0.16	6.57±0.13	51.55±0.16
PB1121	525.06±15.22	153.11±1.05	0.49±0.006	28.57±3.23	2.78±0.07	5.61±0.01	49.07±0.02	-0.79±0.25	6.88±0.18	48.60±0.18
PS17	578.19±8.56	153.01±0.88	0.51±0.006	39.15±6.93	2.78±0.023	5.10±0.01	53.47±0.14	-0.66±0.15	7.63±0.15	52.84±0.07
PB (PB1509)	505.62±10.68	135.15±0.96	0.51±0.006	10.15±0.79	2.28±0.03	6.00±0.14	40.07±0.03	0.89±0.13	12.13±0.08	38.84±0.25
SM	648.15±14.30	128.57±1.13	0.51±0.006	12.23±1.42	2.36±0.04	4.40±0.02	57.67±0.14	-0.89±0.16	6.24±0.14	57.20±0.11
JR	679.00±8.977	130.72±1.44	0.45±0.007	7.13±0.92	2.92±0.02	3.20±0.02	55.71±0.10	-0.91±0.17	5.72±0.11	55.33±0.15
CD	37.777	3.648	0.018	11.393	0.135	0.191	0.317	0.050	0.417	0.503
SE(m)	12.126	1.171	0.006	3.657	0.043	0.061	0.102	0.016	0.134	0.162
SE(d)	17.148	1.656	0.008	5.172	0.061	0.087	0.144	0.023	0.189	0.229
C.V. (%)	3.655	1.430	2.094	28.639	2.810	2.170	0.317	3.527	3.014	0.552
-80°C										
PB1509	555.86±8.87	149.02±0.90	0.48±0.012	43.77±6.35	2.32±0.05	5.40±0.01	50.82±0.20	-0.78±0.02	6.76±0.05	50.35±0.20
PB1121	572.21±10.06	151.90±1.20	0.49±0.012	36.13±6.04	2.32±0.04	5.80±0.02	48.21±0.09	-0.91±0.01	7.27±0.08	47.69±0.17
PS17	592.37±13.60	151.89±1.76	0.51±0.012	44.82±7.65	2.08±0.03	5.20±0.03	50.12±0.05	-0.72±0.02	7.87±0.06	49.49±0.13
PB (PB1509)	548.02±28.24	134.86±1.37	0.50±0.012	14.82±1.71	1.74±0.03	6.00±0.14	38.15±0.07	1.08±0.02	12.56±0.23	36.87±0.11
SM	666.83±8.82	126.15±0.48	0.49±0.006	13.51±2.05	1.82±0.04	4.50±0.04	52.86±0.06	-0.92±0.01	6.62±0.18	52.38±0.22
JR	695.24±12.77	128.05±0.10	0.42±0.006	7.21±0.53	2.39±0.04	3.50±0.02	53.97±0.02	-0.95±0.01	6.74±0.12	53.46±0.16
CD#	47.661	3.487	0.031	15.192	0.110	0.192	0.305	0.040	0.431	0.523
SE(m)	15.298	1.119	0.010	4.876	0.035	0.062	0.098	0.013	0.139	0.168
SE(d)	21.635	1.583	0.014	6.896	0.050	0.087	0.139	0.018	0.196	0.237
CV (%)	4.379	1.382	3.583	31.622	2.906	0.192	0.346	2.503	3.010	0.601

BD: Bulk Density, VE: Volume Expansion, WA: Water activity, DG: Damaged grains, RR: Rehydration ratio, RT: Rehydration time, *L**: lightness, *a**: redness-greenness, *b**: yellowness-blueness, WI: whiteness. #at 5% level of probability

Table 5: Average performance of quality attributes of instant rice at different freezing pretreatments as a function of cultivars

FT (°C)	*BD (kg/m³)*	*VE (%)*	*WA*	*DG (%)*	*RR*	*RT (mins)*	*L**	*a**	*b**	*WI*
-20	547.62	143.97	0.5	15.35	3.08	4.76	55.95	-0.23	7.04	55.35
-50	574.69	141.92	0.49	22.11	2.67	4.91	51.33	-0.49	7.86	50.70
-80	605.09	140.31	0.48	26.71	2.11	5.07	48.66	-0.53	7.97	48.37

FT: Freezing Temperature, BD: Bulk Density, VE: Volume Expansion, WA: Water activity, DG: Damaged grains, RR: Rehydration ratio, RT: Rehydration time, *L**: lightness, *a**: redness-greenness, *b**: yellowness-blueness, WI: whiteness.

Table 6: Average performance of quality attributes of instant rice of different rice cultivars as a function of freezing pretreatment

Cultivar	*BD (kg/m³)*	*VE (%)*	*WA*	*DG (%)*	*RR*	*RT (mins)*	*L**	*a**	*b**	*WI*
PB 1509	519.32	150.71	0.48	33.77	2.83	5.18	53.84	-0.61	6.41	52.39
PB 1121	535.86	153.42	0.48	28.53	2.72	5.58	50.39	-0.80	6.83	49.91
PS17	568.93	153.24	0.52	36.68	2.64	5.10	53.80	-0.28	7.49	53.19
PB (PB1509)	513.28	136.21	0.51	10.78	2.26	5.98	41.35	0.94	12.24	40.00
SM	645.06	128.51	0.51	12.01	2.35	4.40	57.10	-0.86	6.86	56.66
JR	672.35	130.31	0.44	6.55	2.93	3.23	57.13	-0.91	5.90	56.71

BD: Bulk Density, VE: Volume Expansion, WA: Water activity, DG: Damaged grains, RR: Rehydration ratio, RT: Rehydration time, *L**: lightness, *a**: redness-greenness, *b**: yellowness-blueness, WI: whiteness.

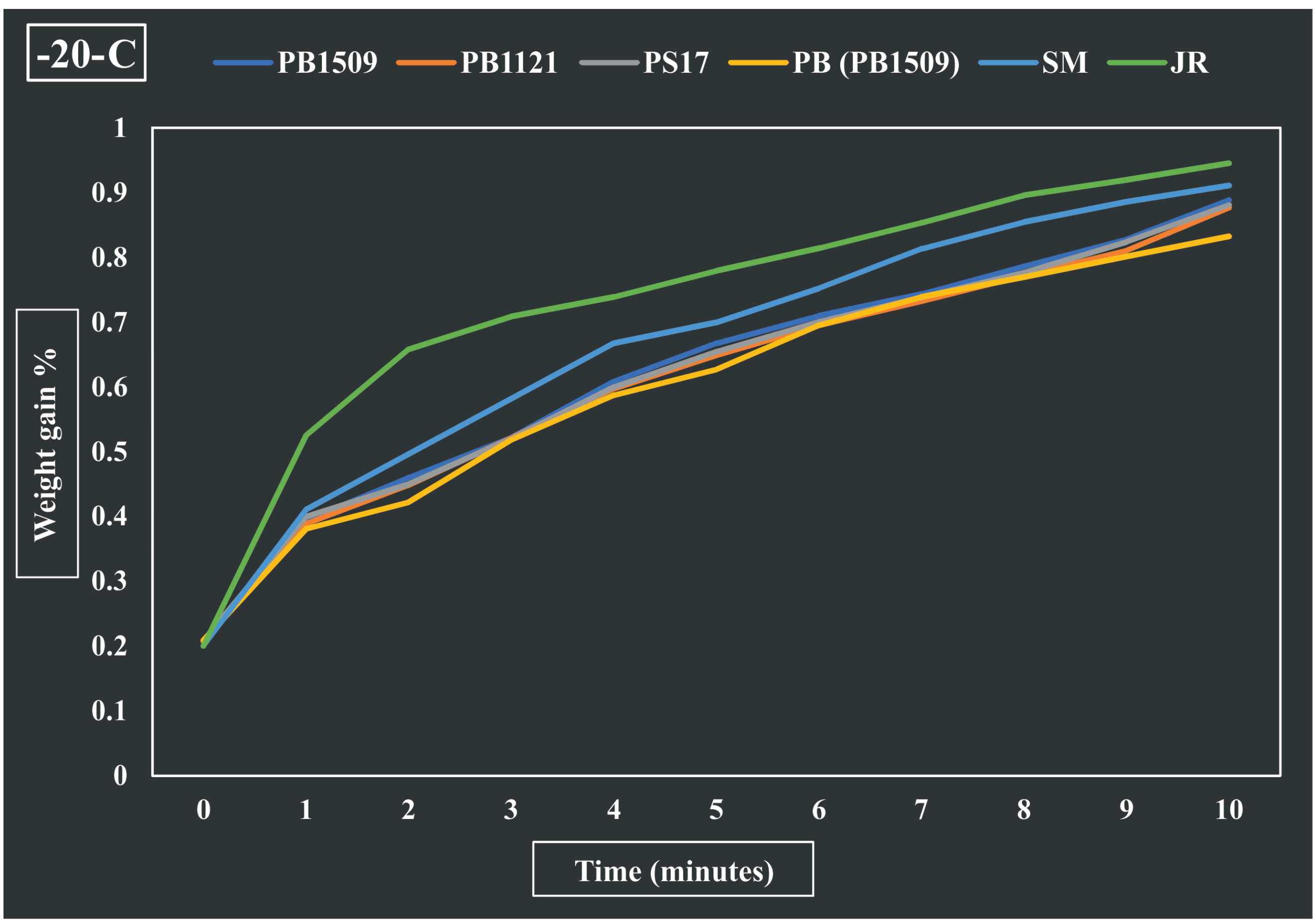

Fig. 1A: Weight gain percentage of instant rice pretreated at -20°C

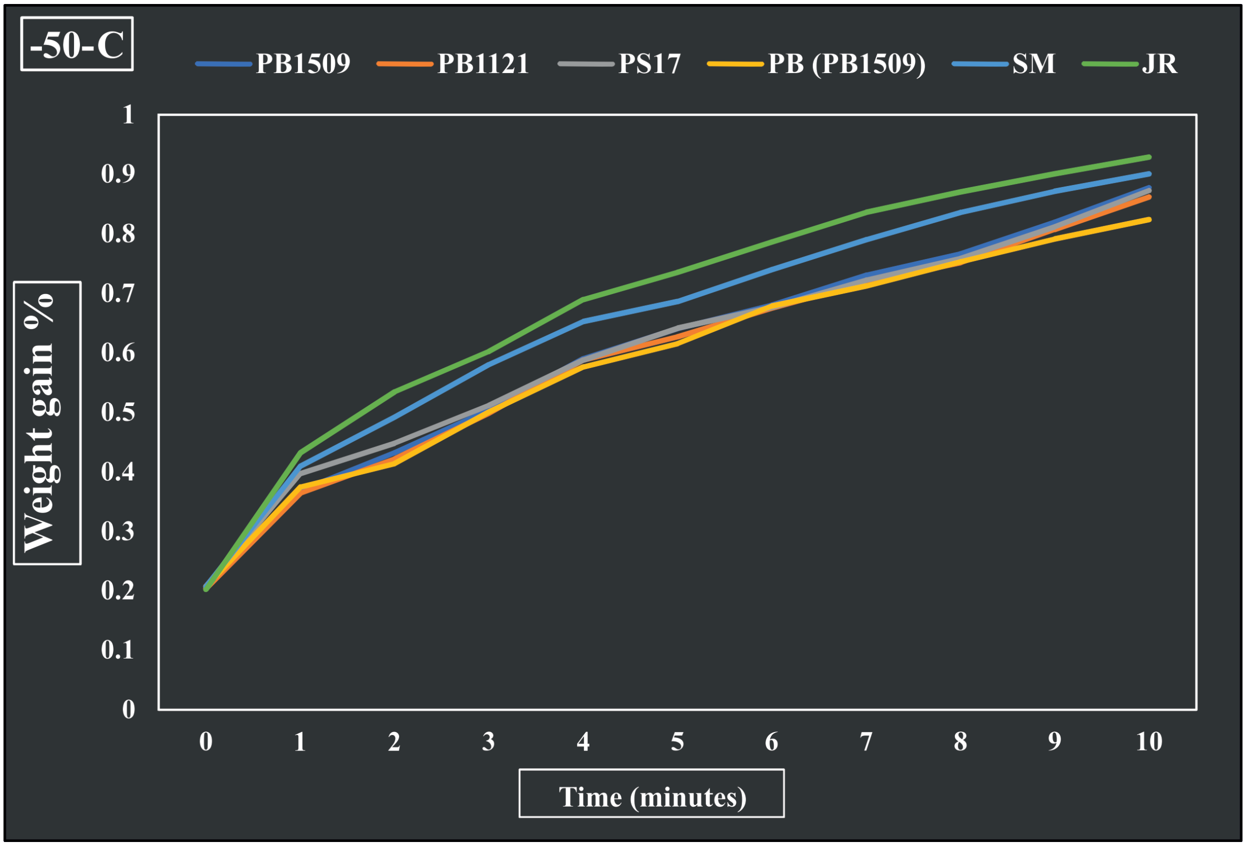

Fig. 1B: Weight gain percentage of instant rice pretreated at -50°C

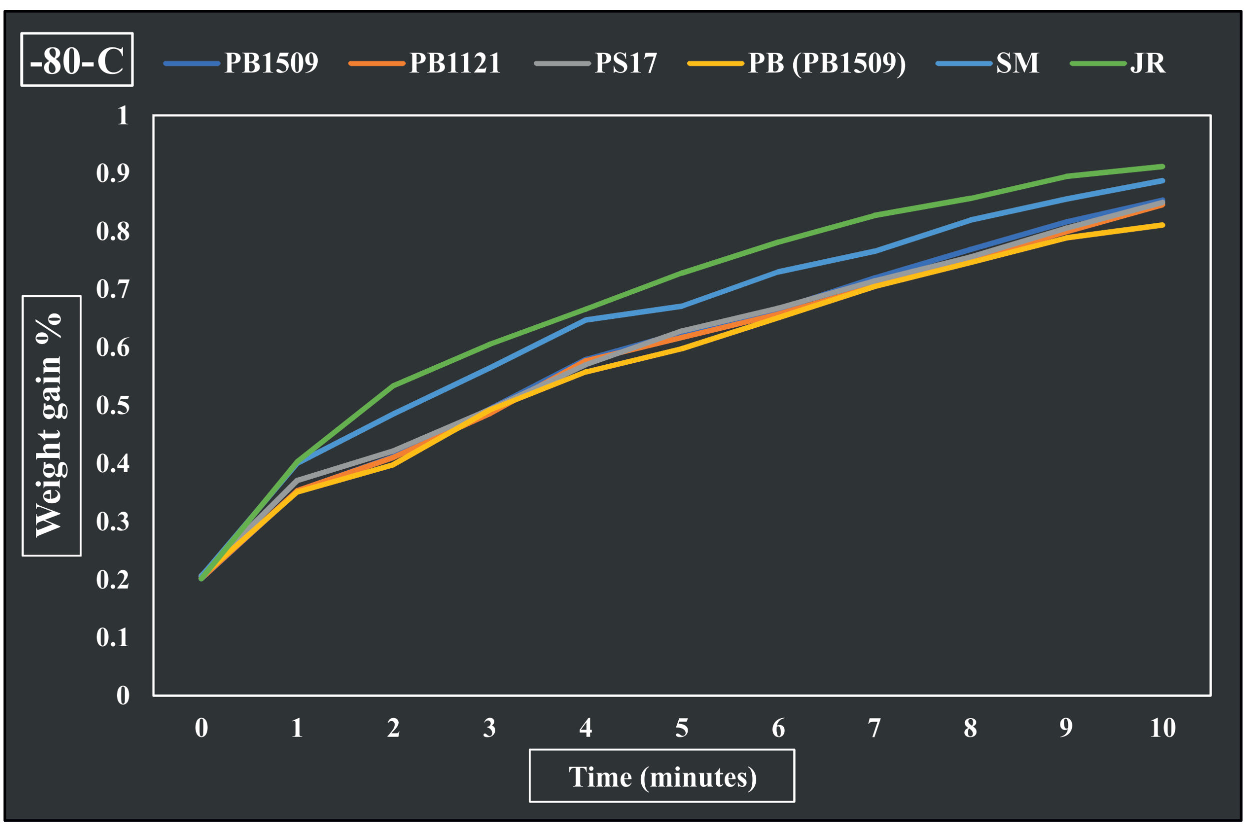

Fig. 1C: Weight gain percentage of instant rice pretreated at -80°C

varietal mean performance, it was observed that rice cultivar JR showed highest values for BD (672.35 kg/m^3), RR (2.93), *L** (57.13) and WI (56.71) and lowest values for WA (0.44), DG (6.55%), RT (3.23 mins), *a** (-0.91) and *b** (5.90). The *basmati* cultivar PB1121 showed highest VE (153.42%). The long grained aromatic non-*basmati* cultivar PS17 showed maximum values for WA (0.52) and DG (36.68%). The instant rice prepared from PB (PB1509) showed highest value for RT (5.98 mins), *a** (0.94) and *b** and lowest values for BD (513.28 kg/m^3), RR (2.26), *L** (41.35) and WI (40). The careful consideration of cultivar choice indicated that the rice cultivar JR emerged as suitable for preparation of instant rice based on optimum quality attributes such as whiteness, lower degree of damaged grains, better rehydration ratio, shortest rehydration time and desirable organoleptic characteristics.

Freezing pretreatments affected the external appearance, color, texture, flavor and overall sensory acceptability for all cultivar. Slow frozen rehydrated instant rice samples had higher scores for all sensory parameters and overall acceptability for all rice cultivar. Rewthong *et al.* 2011 showed that samples pretreated at -20°C were similar to freshly cooked rice in terms of texture and flavor.

CONCLUSION

Freezing rate and temperature had a profound effect on the quality attributes of instant rice. Slow freezing rate at a freezing temperature of -20°C was found suitable for producing instant rice with better rehydration characteristics. Analysis of physico- chemical variation in different rice cultivars revealed that longer grains took higher time to rehydrate while shorter and medium grains took less time to rehydrate. As per organoleptic parameters, instant rice prepared from *Basmati* rice cultivars are the preferred choice of most of the consumers, however, more rehydration time is disadvantageous for these cultivars. Comparable to *basmati* cultivars, *Jeerakasala* cultivar, besides exhibiting least time duration for rehydration, also possess good aroma, well separated grains and lower degree of damaged grains proved to be an optimal choice for development of instant rice and preparation of instant rice products such as instant rice *kheer*, *pulav*, *biryani*, etc. Among the treatments studied, the best suitable choice for preparation of instant rice turned out to be *Jeerakasala* cultivar with slow freezing at -20°C, followed by drying at 70°C in a fluidized bed drier until attainment of 5% moisture content level.

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