Effect of Freezing Temperature and Duration on Physicochemical Characteristics of Instant Rice

K S Sasmitaloka¹*, S Widowati¹, and E Sukasih¹

¹Indonesian Center for Agricultural Postharvest Research and Development, Jln. Tentara Pelajar No. 12, Bogor 16114

*Email: kirana.sanggrami@gmail.com

Abstract. Instant rice is becoming more popular in modern lifestyle. This study investigated the effect of freezing temperature and duration on physicochemical characteristics of instant rice. Raw material used in this study was rice with two different amylose content, i.e. high (> 25%) and intermediate (20-25%). The experiment was conducted in randomized block design with treatments of freezing temperature (-20 and -4°C) and time (12, 18, and 24 hour), with three replications. The results of analysis of variance (ANOVA) showed that between freezing temperature and duration were significantly different of their physicochemical characteristics (p<0.05). The best freezing temperature and duration for both of rice was -4°C for 24 hour. Characteristics of instant rice from high amylose were rehydration time of 4.97 minutes, rehydration ratio of 3.14, density of 0.55 gr/ml, volume expansion of 178.99%, water absorption 55.44%, and yield recovery of 88.67%. This product contained of 6.57% moisture, 0.40% ash, 0.21% fat, and 7.92% protein. While, characteristics of instant rice from intermediate amylose were rehydration time of 4.07 minutes, rehydration ratio of 3.29, density of 0.57 gr/ml, volume expansion of 169.64%, water absorption 56.90%, yield recovery of 92.05%. This product contained of 7.58% moisture, 0.70% ash, 0.42% fat, and 7.92% protein.

1. Introduction
Rice is widely consumed as a staple food in Asia [1]. Nowadays, more than 50% of the world’s population is consuming rice. Rice has many advantages such as high of carbohydrate, vitamin and mineral content, and various contents of amylose and amylopectin. Generally rice contains of 78% carbohydrate, 6.7% protein, 3.6% fat, 0.4% fibbers, 0.41% vitamin B1, 0.02 mg of vitamin, and 5.8 mg niacin per 100g [2].

Instant food is becoming more popular. In the era of industrialization, humans are required to move quickly, including in preparing food every day. Instant food is also needed when natural disasters occur. For this reason, we can promote new ways to consume rice in modern lifestyle, such as instant rice. It is produced from a conventional process consists of soaking in sodium citrate solution, washing, cooking, freezing, and drying [3]. Instant rice takes only a few minutes (less than 5 minutes) to prepare for consumption after rehydration [4].

Instant rice needs to be rehydrated and its quality after rehydration is very important to consumer acceptability [3]. However, instant rice production is still facing problems with rehydration time and quality. These problems might be caused by the preparing process of instant rice. Soaking in sodium citrate solution, cooking and drying affected the physicochemical properties of instant rice [5, 6, 7].
Freezing is frequently used as a means to treat food products. In instant rice production, freezing is known to provide high-quality rice, retard starch retrogradation [8, 9], and provide minimal damage of the cell walls of plants and thus maintains their texture [9, 10]. Rewthong et al., [3] stated that freezing at temperature of -20°C for 24 hour in instant rice production causes rice texture to be produced similar to ordinary rice (not instant rice). Furthermore, Song et al., [11] and Luna et al., [12] suggested that the best condition to produce instant rice is freezing at temperature of -4°C for 24 hour. But no studies have examined the effect of freezing temperature and duration in instant rice production. Therefore, this research studied the effect of freezing temperature and duration to the physicochemical characteristics of instant rice.

Based on amylose content, rice is categorized into three groups, i.e. low amylose (<20%), intermediate amylose (20-24%), and high amylose (>25%) contents [13]. Luna et al., [12] stated that most of the rice in tropical country has an amylose content of more than 20%. Therefore, this study used two types of rice, i.e. high and intermediate amylose rice, to represent types of rice that are consumed in tropical country. The aim of this research was to study the effect of freezing temperature and duration to physicochemical characteristics of instant rice.

2. Methods

2.1. Materials
Raw materials used in this research were Inpari 32 and IR 42 rice varieties, obtained from Indonesian Center for Rice Research (ICRR), Subang, West Java. The chemical used as soaking solution was 5% sodium citrate solution (technical grade). Equipment used were digital balance, freezer, and cabinet dryer.

2.2. Instant Rice Production
Instant rice was prepared according to the methods of Widowati et al., [14] and Kyritsi et al., [15]. Inpari 32 or IR 42 rice (500 gram) was soaked in 5% sodium citrate solution (technical grade) with a ratio of rice: sodium citrate solution of 1: 2 for 2 hours. Then rice was washed to remove sodium citrate residue. Afterwards, rice was cooked using rice cooker until well cooked and left to cool, before being loaded into the freezer. Frozen rice was then thawed, and then was dried in cabinet dryer.

In the freezing process, two treatments were used, namely temperature and freezing duration. The freezing temperature used consists of -4 and -20°C. While the freezing duration used consists of 12, 18, and 24 hours.

2.3. Analysis
Sample analysis was conducted for rice as raw material and instant rice as a product. Raw material analysis included proximate analysis [16] and amylose content [17]. Moreover, instant rice were analyzed for its performance, i.e. rehydration time [18], yield recovery [12], density [6], water absorption [19], volume expansion [19], rehydration ratio [6], and proximate analysis [16]. All data were subjected to the analysis of variance (ANOVA) using SAS 9.1.3 version. Differences between mean values were established using Duncan’s multiple range tests at a confidence level of 95%. All experiments were performed in triplicates.

3. Results and Discussion

3.1. Raw materials characterization
Proximate analysis of Inpari 32 and IR 42 rice varieties were carried out to find out the condition of raw materials (Table 1). Based on Table 1, both of rice can be used as raw materials of instant rice productions.
Table 1. Characteristics of Inpari 32 and IR 42 rice varieties

| Parameters       | Inpari 32       | IR 42         |
|------------------|-----------------|---------------|
| Moisture (%)     | 10.03±0.02      | 12.06±0.11    |
| Ash (%)          | 0.53±0.02       | 0.76±0.05     |
| Fat (%)          | 0.82±0.04       | 0.75±0.03     |
| Protein (%)      | 10.10±0.01      | 8.78±0.03     |
| Carbohydrate (%) | 78.53±0.06      | 77.66±0.21    |
| Amylose (%)      | 23.27±0.44      | 26.8±0.25     |

Amylose is the main parameter that determines rice quality. Rice with high amylose content will produce higher hardness and less sticky after cooled, while low amylose rice will produce lower hardness and more sticky [20]. Based on amylose content, Inpari 32 rice variety is classified in intermediate amylose rice and IR 42 rice variety in high amylose rice.

3.2. Rehydration time

Rehydration time is the time needed for the material to re-absorb water to obtain a homogeneous texture [21]. The longer of freezing temperature and duration, the shorter of rehydration time needed (Figure 1). Statistical analysis results showed that temperatures, freezing durations, and interaction between temperatures and freezing duration were significantly different for rehydration time, both of instant rice.

Porosity is one of important factors that affect the nature of instant product. A more porous structure will accelerate the hot water enters when it was rehydrated. After rehydration, instant rice is expected to have the appearance of ordinary rice in terms of taste, aroma, and texture [3, 6]. More porous instant rice will simplify and speed up the rehydration time.

![Figure 1](image1.png)

**Figure 1.** Rehydration time of instant rice: (a) Inpari 32; and (b) IR 42

Freezing process was carried out to produce high porosity of instant rice. Freezing and frozen storage will increase the expansion of starch molecules through hydrogen bonds. This process will release the water contained in the gel system. Thawing process will produce micro sponge solid structure. After drying process, this porous dry solid can be quickly gelatinized during rehydration with hot water [22]. The best temperature and freezing duration for both of instant rice was -4°C for 24 hours. This condition produced rehydration time of 4.97 minutes for IR 42 instant rice variety and 4.07 minutes for Inpari 32 rice variety.

3.3. Yield

Yields of instant rice can be affected by soaking solution that used. Luna *et al.*, [12] stated that soaking rice in sodium citrate solution can destroy or decompose rice protein structure. This leads to more porous rice and decrease the the yield of instant rice. In this study, the concentration of sodium citrate solution used for each treatment was 5%. This caused the yield produced for each treatment was similar (Figure 2).
However, longer freezing duration resulted in higher yield. Statistical analysis results showed that temperatures, freezing durations, and interaction between temperatures and freezing durations were not significantly different from yields, both for Inpari 32 and IR 42 rice varieties.

![Graph](image)

Figure 2. Yields of instant rice: (a) Inpari 32; and (b) IR 42

3.4. Density
Density is one of the physical properties of food that needs to be studied, especially for packaging, storage and transportation. This can indicate empty space which is the number of empty cavities between material particles. The greater the density produced, the less the number of voids it has [23]. The product will be more porous if the density is smaller. Density of instant rice showed in Figure 3.

![Graph](image)

Figure 3. Density of instant rice: (a) Inpari 32; and (b) IR 42

A long freezing duration would produce the structure of instant rice that was more porous with a smaller density. This condition is in line with the results of research by Husein et al., [24] which stated that the freezing method will produce a lower density. According to Singh and Heldman [25] ice density is lower than water density. So that food products that undergo a freezing process will have a lower density than without freezing. Statistical analysis showed that freezing duration had an effect for density both of instant rice. Temperatures and interaction between temperatures and freezing duration did not affect the density of instant rice.

3.5. Water absorption
When starch was gelatinized, water that was initially outside the granule and frees to move would enter the starch and could not move freely. The water component in the matrix would evaporate leaving the matrix when the starch was dried. This causes the starch to become porous and can easily re-absorb water. An increase in effective water diffusion occurs when the granule structure becomes more open and porous [26]. Water absorption of instant rice showed in Figure 4. Statistical analysis showed that
the freezing durations was significantly different for water absorption both of instant rice. Temperatures and interaction between temperatures and freezing durations did not affect the water absorption for both of instant rice.

Figure 4. Water absorption of instant rice: (a) Inpari 32; and (b) IR 42

3.6. Volume expansion

Volume expansion of instant rice was an increase in volume caused by water absorption of rice during rehydration. Porosity and water absorption of a material would affect the volume expansion. According to Muramatsu et al., [27], during the water absorption process, there is a change in the shape of rice particles as a result of expansion. Material with high porosity and water absorption will produce its high volume expansion.

Freezing process will increase volume expansion of instant rice (Figure 5). Instant rice with longer freezing duration would produce higher volume expansion. Statistical analysis showed that freezing temperatures did not affect the volume expansion of instant rice. Interaction between temperatures and freezing durations were significantly different for volume expansion of instant rice.

Volume expansion was caused by expansion of starch granules. During instant rice rehydration, hot water would enter the porous instant rice structure. Addition of hot water causes gelatinization and expansion of starch granules. The volume of rice starch granule expansion during rehydration is not as large as the starch expansion capacity which can be 64 times greater than that of native starch [27].

Figure 5. Volume expansion of instant rice: (a) Inpari 32; and (b) IR 42
3.7. Rehydration ratio

Rehydration ratio shows the ability of a material to re-absorb water after dried. Higher rehydration ratio of a product shows the more water absorbed by the dry product [28]. Where more water is absorbed by a material, the rehydration ratio will also increase. Rehydration ratio is negatively correlated with its density [6, 29]. The rehydration process occurs faster due to an increase in surface area that is in line with increasing volume. Good rehydration in instant product is obtained with high levels of rehydration and short rehydration time. Statistical analysis results showed that freezing durations was significantly different for rehydration ratio of instant rice. Longer freezing duration will produce higher rehydration ratio (Figure 6). Temperatures and interaction between temperatures and freezing durations did not affect for rehydration ratio both of instant rice.

![Figure 6. Rehydration ratio of instant rice: (a) Inpari 32; and (b) IR 42](image)

3.8. Proximate analysis

This freezing process caused changes in the chemical content of instant rice (Table 2 and Table 3). In general, changes in the chemical content of instant rice were affected by freezing time, and were not affected by freezing temperatures. The results of statistical analysis showed that the freezing duration produced significantly different water content and carbohydrate content (Table 2 and Table 3). While the ash, fat, and protein contents which produced in instant rice production were not significantly different from the freezing temperature and duration.

| Treatments                     | Moisture Content (%) | Ash Content (%) | Fat Content (%) | Protein Content (%) | Carbohydrate Content (%) |
|--------------------------------|----------------------|-----------------|-----------------|---------------------|--------------------------|
| Freezing at -4°C, 24 hours     | 7.58±0.11           | 0.70±0.07       | 0.42±0.08       | 9.22±0.06           | 82.08±0.16               |
| Freezing at -4°C, 18 hours     | 6.96±0.16           | 0.64±0.08       | 0.31±0.07       | 9.40±0.12           | 82.69±0.09               |
| Freezing at -4°C, 12 hours     | 6.33±0.11           | 0.40±0.07       | 0.47±0.01       | 9.33±0.11           | 83.47±0.23               |
| Freezing at -20°C, 24 hours    | 7.67±0.04           | 0.43±0.01       | 0.38±0.05       | 9.37±0.21           | 82.16±0.15               |
| Freezing at -20°C, 18 hours    | 6.98±0.55           | 0.26±0.05       | 0.32±0.08       | 9.27±0.17           | 83.18±0.41               |
| Freezing at -20°C, 12 hours    | 6.60±0.09           | 0.45±0.05       | 0.47±0.06       | 7.33±0.53           | 85.14±0.48               |

Remark: Different letters on the same lines indicate significantly different (p<0.05)
Very significant changes in water content occur because of the porous structure of instant rice, due to the soaking process in sodium citrate and the freezing process. Soaking rice in sodium citrate solution produces a pore structure that causes the movement of water to the inside of the rice endosperm, through the dorsal kernel vascular [30]. Thawing after the freezing process will result in a solid structure of micro sponges. This causes the water to become easier to get out of instant rice during the drying process. Carbohydrate content is also significantly different during the process of instant rice production. The freezing process will produce ice structures that can break down the structure of colloidal starch [26]. Breaking the structure of rice starch into a simpler structure causes an increase in carbohydrate content.

### Table 3. Proximate characteristics of IR 42 instant rice variety

| Treatment                        | Moisture (%) | Ash (%) | Fat (%) | Protein (%) | Carbohydrate (%) |
|----------------------------------|--------------|---------|---------|-------------|------------------|
| Freezing at -4°C, 24 hours       | 6.59±0.91 A(a) | 0.40±0.04 A(a) | 0.21±0.02 B(a) | 7.92±0.33 A(a) | 84.88±1.14 A(a) |
| Freezing at -4°C, 18 hours        | 5.84±0.27 B(b) | 0.42±0.05 A(a) | 0.16±0.02 B(a) | 7.98±0.10 A(a) | 85.60±0.40 A(a) |
| Freezing at -4°C, 12 hours        | 5.21±0.07 C(b) | 0.41±0.03 A(a) | 0.63±0.09 A(a) | 7.99±0.19 A(a) | 85.76±0.10 A(b) |
| Freezing at -20°C, 24 hours       | 6.96±0.15 A(a) | 0.46±0.03 A(a) | 0.22±0.04 B(a) | 7.91±0.21 A(a) | 84.45±0.33 C(a) |
| Freezing at -20°C, 18 hours       | 5.92±0.15 B(b) | 0.26±0.03 C(b) | 0.19±0.01 B(a) | 8.01±0.05 A(a) | 85.62±0.14 B(a) |
| Freezing at -20°C, 12 hours       | 5.24±0.22 C(a) | 0.37±0.01 B(b) | 0.15±0.05 B(b) | 7.67±0.31 A(a) | 86.56±0.27 A(a) |

Remark: Different letters on the same lines indicate significantly different (p<0.05)

### 3.9. Determination of the selected freezing condition

The main parameter in determining the selected temperature and freezing duration is rehydration time (maximum 5 minutes). Based on the results of the rehydration time test, instant rice from intermediate amylose rice content with a maximum rehydration time of 5 minutes was freezing treatment temperature of -4°C for 24 hours (4.07 minutes), -20°C for 24 hours (4.07 minutes), and -20°C for 18 hours (4.03 minutes). Results showed that ANOVA between the three treatments were not significantly different of their rehydration time (p<0.05). So, the best selected treatment was freezing at -4°C for 24 hours, because the energy requirement would be greater if the freezing was carried out at -20°C for 18 hours. This condition also applied to instant rice from high amylose rice content.

### 4. Conclusions

In instant rice production, the best temperature and freezing duration for both types of rice was -4°C for 24 hours. Characteristics of instant rice from high amylose were rehydration time of 4.97 minutes, rehydration ratio of 3.14, density of 0.55 gr/ml, volume expansion of 178.99%, water absorption 55.44%, and yield recovery of 88.67%. This product contained of 6.57% water, 0.40% ash, 0.21% fat, and 7.92% protein. While, characteristics of instant rice from intermediate amylose were rehydration time of 4.07 minutes, rehydration ratio of 3.29, density of 0.57 gr/ml, volume expansion of 169.64%, water absorption 56.90%, yield recovery of 92.05%. This product contained of 7.58% water, 0.70% ash, 0.42% fat, and 7.92% protein.
5. References

[1] Byun Y, Hong SI, Mangalasaary S, Bae HJ, Cooksey K, Park HJ and Whiteside S 2010 LWT-Food Sci. Technol. 43 852-866
[2] Food Standards Agency and Institute of Food Research 2002 Mc Cance and Widdowson’s The Composition of Foods, Sixth Summary Edition. Royal Society of Chemistry, Cambridge
[3] Rewthong O, Soponronnarit S, Taechhapairoj C, Tungtrakul P and Prachayawasakorn S 2011 J. Food Eng. 103 258 – 264
[4] Wang JP, An HZ, Jin ZY, Xie ZJ, Zhuang HN and Kim JM 2011 J. Food Sci. Technol. 50(4): 655-666
[5] Sirisootarala K, Nakornpanom NN, Koakietdumrongkul K and Panumaswiwath C 2015 LWT-Food Sci. Technol. 61 138-144
[6] Prasert W and Suwannaporn P 2009 J. Food Eng. 95(1): 54-61
[7] Derycke V, Vandeputte GE, Vermeylen R, Deman W, Goderis B, Koch MHJ and Delcour JA 2005 J. Cereal Sci. 42 334–343
[8] García-Alonso A, Jiménez-Escrig A, Martín-Carrón N, Bravo L and Saura-Calixto F 1999 Food Chem. 66 181–187
[9] Yu S, Ma Y, Liu T, Menager L, and Sun DW 2010 J. Food Eng. 96 416–420
[10] Chassagne-Berces S, Poirier C, Devaux MF, Fonseca F, Lahaye M, Pigorini G, Girault C, Marin M, and Guillot F 2009 Food Research Int. 42 788–797
[11] Song BS, Park JN, Lee JW, Kim JK, Kim JH 2014 J Food Proc. and Pres. 38 1244-1250
[12] Luna P, Herawati H, Widowati S, and Prianto AB 2015 J. Pascapanen Pertanian. 12 (1) 1-10
[13] Meullnett JF, BP Marks, JA Hankins, VK Griffin and MG Daniels 2000 Cereal Chem. 77 259-263.
[14] Widowati S 2008 PANGAN BULOG. 17 (52) 51-60
[15] Kyritsi A, Tzia C and Karathanos 2011 LWT-Food Sci. Tech. 44 312-320
[16] AOAC (Association of Official Analytical Chemist) 2006 Official Methods of Analytical of The Association of Official Analytical Chemist. Washington, DC: AOAC.
[17] Juliano BO 1971 Cereal Sci. Today. 16 334-336
[18] Sudarmadji S, Haryono B and Suhardi 2007 Analysis Procedures for Foodstuffs and Agriculture [In Bahasa Indonesia] (Yogyakarta: Liberty Press).
[19] Butt MS, Anjum FM, Salim-ur-Rehman, Tahir-Nadeem M, Sharif MK, and Anwer M 2008 Int. J. Food Prop. 11 (3) 698-711
[20] Yu S, Ma Y, and Sun DW 2009 J. Cereal Sci. 50 139–144
[21] Yu KC, Chen CC and Wu PC 2011 J. App. Sci. 11 535–541
[22] Kumalasari R, Setyoningrum F, and Ekafitri R 2015 PANGAN. 24 (1) 27-48
[23] Hui YH, Clary C, Farid MM, Fasina OO, Noomhorm A, and Welti-Chanes J 2007 Food Drying Science and Technology: Microbiology, Chemistry, Application (Lancaster: Destech Publications, Inc).
[24] Husain H, Muchtadi TR, Sugiyono and Haryanto B 2006 J. Teknologi dan Industri Pangan. 17 189–196
[25] Singh RP and Heldman DR 2001 Introduction to Food Engineering (London: Academic Press).
[26] Taghinezhad F, Khoshtaghaza MH, Minaei S, Suzuki T and Brenner T 2016 Rice Science. 23 339–344
[27] Muramatsu Y, Tagawa A, Sakaguchi E and Kasai T 2006 Cereal Chem. J. 83 (6) 624-631
[28] Asgar A and Musaddad D 2006 J. Hort. 16 (3) 245-252
[29] Leelayuthsoontorn P and Thipayarat P 2006 Food Chem. J. 96 606–613
[30] Promthai C, Huang L, Glahn RP, Welch RM, Fukai S and Rerkasem B 2006 J. Sci. Food Agr. 86 (8) 1209-1215