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Vacuum Impregnated Rice as Affected by Moisture Contents and Rice Varieties

*Chanettee Makmuang, Aphirak Phianmongkhol and Tri I. Wirjantoro**

Division of Food Science and Technology, Faculty of Agro-Industry, Chiang Mai University, Thailand

**Corresponding author: triindrarini.w@cmu.ac.th; tiwirjantoro@gmail.com*

Abstract

Rice is an economical commodity for Thailand. Although it is common to directly consume the rice, its commercial value can be increased through processing, such as vacuum impregnation. Therefore, the aim of this study was to investigate the effect of moisture contents and rice types on the physicochemical properties of vacuum impregnated rice. Four different rice varieties, including white rice (*Sao Hai*), white glutinous rice (*Kiaw Ngu*), black rice (*Hom Nin*) and black glutinous rice (*Kum Doi Saket*), were cooked in an electric cooker at different water addition to produce cooked rice with moisture contents of approximately 50 or 60%. The cooked rice was then subjected to vacuum impregnation at 50 mbar for 10 min in an impregnation solution of saline solution at a ratio of 1:2 for rice and water, respectively, followed by another 10 min period in the solution as a relaxation time. Physicochemical analyses of the impregnated rice showed that different rice varieties and moisture contents of cooked rice significantly affected hardness, rice volumetric deformation (γ value), volume of rice occupied by impregnation solution (X value), real porosity (ϵ_r), solid gain and water loss ($p < 0.05$). The white glutinous rice with a moisture content of $50.71 \pm 0.30\%$ significantly had the highest γ and X values of $1.00 \pm 0.64 \text{ m}^3/\text{m}^3$ initial sample and $1.15 \pm 0.04 \text{ m}^3 \text{ liquid}/\text{m}^3 \text{ sample}$, respectively. This rice treatment also significantly possessed the lowest water loss ($-94.97 \pm 3.06\%$), whereas the highest solid gain of $2.45 \pm 0.16\%$ was determined in the white rice with a moisture content of $49.50 \pm 0.55\%$. For the ϵ_r value, the lowest value of this parameter ($0.022 \pm 0.018\%$) was found in the black glutinous rice with a moisture content of $50.14 \pm 0.22\%$. Finding from this study clearly suggested rice varieties and moisture contents of cooked rice are important parameters in the application of vacuum impregnation.

Keywords : *Rice varieties, Moisture content, Vacuum impregnation, Physicochemical properties.*

1. Introduction

Rice is the staple food of nearly half of the world's population (Song et al., 2013). Rice can be separated into two types, which are non-glutinous and glutinous rice types. The non-glutinous white rice is the most popular rice variety in Thailand (Rewthong et al., 2011). Glutinous rice or waxy rice is utilized as part of basic food only in several countries, such as Laos, northern part of Thailand, Cambodia, Vietnam and Myanmar (Bhattacharya, 2011). Beside white rice, coloured rice, such as black rice, red rice and brown rice, are also known and available in the commercial market. These rice types are reported as potent sources of antioxidants and nutritional advantages over common rice (Sompong et al., 2011). Rice kernels have a low distribution of micro pores within and among the starch granules. Through these micro pores, small molecules, such as water, can naturally penetrate into the dense matrix of the kernel. (Mee-ngern et al., 2014). Vacuum Impregnation (VI) technology can be used to incorporate physiologically active components, such as prebiotic, probiotic, vitamin or mineral, into structure of fruit and vegetable (Betoret et al., 2003). Developing of fruit enriched with probiotic using VI technique had been reported by Betoret et al. (2003), Krasaekoopt and Buthanwong (2008), Piromvard et al. (2010) and Noorbakhsh et al. (2013). Hironaka et al. (2011) applied the VI technology to fortify ascorbic acid into whole potatoes. For an application of vacuum drying in rice, it was reported by Mee-ngern et al. (2014) that introduced a beetroot juice into white rice kernels both of non-glutinous (Khao Dawk Mali 105, Chainat 1) and glutinous (Sanpatong 1)

variety. The researchers reported that there was a significant increase in antioxidative activities for all impregnated rice varieties. Beside these research works, there is less reports that studied pretreatment of rice samples during VI treatment. Therefore, this research has an objective to investigate the effect of moisture contents and cooked rice varieties on the physicochemical parameters of impregnated rice.

2. Materials and Methods

2.1 Cooked rice

Four Thai rice varieties, including white rice (Sao Hai), white glutinous rice (Kiaw Ngu), black rice (Hom Nin) and black glutinous rice (Kum Doi Saket) were purchased from a local supermarket in Chiang Mai, Thailand. All rice varieties were cooked by an automatic electric cooker (Panasonic SR-G06, Japan) in various water to rice ratio or soaking time to produce cooked rice with moisture contents of approximately 50 and 60% (wet basis). Determination of final moisture contents of cooked rice followed the method of Luangmalawat et al. (2008).

2.2 Vacuum impregnation treatment

Vacuum impregnation was applied to all cooked rice using a vacuum oven (Binder VD23, Germany). During the impregnation process, cooked rice was immersed in impregnation solution at a ratio of 1:2 (w/w) (Noorbakhsh et al., 2013) for cooked rice and saline solution that had an a_w similar to the cooked rice, which was referred as an isotonic solution (Guillemin et al., 2008). A vacuum pressure of 50 mbar was applied for 10 min, followed by a restoration to atmospheric pressure for another 10 min (Betoret et al., 2003). After the treatment, cooked rice was separated by

a sieve from the saline solution and drained at room temperature for up to 30 min. The vacuum impregnated rice was kept at 4°C to be analysed.

2.3 Physicochemical analyses

Texture of vacuum impregnated rice was determined as hardness (N) using a Texture Analyzer (TA-Xt.Plus, Stable Micro systems, Surrey, UK), based on the compression model (85% deformation) at 25°C. The amount of liquid impregnated into rice samples (X) (Rongkom et al., 2013) and volumetric deformation of the sample (γ) (Krasaekoopt and Suthanwong, 2008) were calculated using equations (1) and (2), respectively.

$$X = \frac{(M_f - M_i)}{\rho_s V_o} \quad (1)$$

Where X was impregnated sample volume fraction, M_f was final mass of cooked rice (kg), M_i was initial mass of cooked rice (kg), ρ_s was density of impregnation solution (kg/m³) and V_o was initial volume of the sample (ml).

$$\gamma = \frac{(V_t - V_o)}{V_o} \quad (2)$$

Where V_o was initial volume of sample (m³) and V_t was final volume of sample (m³). The determination of volumes of rice samples was carried out using a method of Yan et al. (2007), based on liquid pycnometry with toluene as a solution. For effective porosity (ϵ_e) and real porosity (ϵ_r), they were calculated using equations (3) and (4), respectively, from the method of Krasaekoopt and Suthanwong (2008).

$$X - \gamma = \epsilon_e \left(1 - \frac{1}{r}\right) - \frac{\gamma}{r} \quad (3)$$

Where ϵ_e was effective porosity and r value was a compression ratio from the calculation of atmospheric pressure divided with vacuum pressure (Rongkom et al., 2013).

$$\epsilon_r = \frac{(\rho_r - \rho_a)}{\rho_r} \quad (4)$$

Where ρ_r was real density (kg/m³) and ρ_a was apparent density (kg/m³). Water loss (WL) and solid gain (SG) were calculated using equations (5) and (6), respectively (Rongkom et al., 2013).

$$WL = \frac{(W_{wo} - W_w)}{W_o} \times 100 \quad (5)$$

Where W_{wo} was initial weight of water in the sample (kg), W_w was weight of water in the sample at the end of treatment (kg) and W_o was initial weight of the sample (kg)

$$SG = \frac{(W_s - W_{so})}{W_o} \times 100 \quad (6)$$

Where W_{so} was initial weight of dry solid in the sample (kg), W_s was weight of dry solids at the end of treatment (kg) and W_o was initial weight of the sample (kg).

2.4 Statistical analysis

The experiment was set up using a Factorial Design with three replications. Analysis of variance was performed using a SPSS statistics base 17.0 for Windows serial number 5068035 (SPSS Inc., Chicago, USA). Differences between the treatment means were determined by

Duncan's Multiple Range Test and statistical significance between sample treatments was defined at $P < 0.05$.

3. Results

3.1 Cooking condition of raw rice

Pretreatment conditions used to soak and cook different rice varieties are

presented in Table 1. In this study, predetermined moisture contents of 50 and 60% were selected. The results in Table 1 showed that the actual moisture content values, which were between 49.50 and 63.29%, were closed to the predetermined values.

Table 1. Cooking condition of different rice varieties

Rice varieties	Soaking and cooking conditions	Moisture content (% , wet basis)
White rice	No soaking, R:W*, 1:1w/v	49.50±0.55 ^a
	No soaking, R:W, 1:1.7w/v	60.46±0.40 ^d
White glutinous rice	1 h soaking, R:W, 1:0.5w/v	50.71±0.30 ^b
	1 h soaking, R:W, 1:1w/v	59.67±0.93 ^d
Black rice	No soaking, R:W, 1:2.5w/v	52.92±0.00 ^c
	No soaking, R:W, 1:3.25w/v	63.29±0.20 ^e
Black glutinous rice	2.19 h soaking, R:W, 1:1.5w/v	50.14±0.22 ^{ab}
	3 h soaking, R:W, 1:3w/v	60.11±0.49 ^d

*R:W is rice to water ratio.

^{a-e} Values followed by different letters within the column are significantly different ($p < 0.05$).

3.2 Physicochemical properties of vacuum impregnated rice

The volume of rice sample that was impregnated with external solution (X value) and the rice volumetric deformation (γ value) in Table 2 showed that different rice varieties and initial moisture contents significantly affected the measured parameters ($p < 0.05$). The highest X and γ values were determined in the white glutinous rice with 50.71% moisture content that had values of $1.15 \pm 0.04 \text{ m}^3 \text{ liquid/m}^3 \text{ sample}$ and $1.00 \pm 0.06 \text{ m}^3/\text{m}^3$ initial

sample, respectively. On the other hand, the black glutinous rice with 60.11% moisture content had the lowest X and γ values of $0.14 \pm 0.06 \text{ m}^3 \text{ liquid/m}^3 \text{ sample}$ and $0.10 \pm 0.02 \text{ m}^3/\text{m}^3$ initial sample, respectively. Effective (ϵ_e) and real (ϵ_r) porosities of vacuum impregnated rice are also displayed in Table 2. The ϵ_r values were significantly affected by different rice varieties and moisture contents investigated in this study ($p < 0.05$), but the ϵ_e values of different rice treatments were not significantly influenced ($p \geq 0.05$). The highest ϵ_r value of

0.165±0.059% was found in the white glutinous rice with 59.67% moisture content, while the lowest one was determined in the black glutinous rice with 50.14% moisture content that had a value of 0.022±0.018%. Different rice varieties and

moisture contents also significantly affected rice ($p<0.05$; Figure 1). Higher

hardness values were determined at lower moisture contents of the rice treatments. The highest hardness value of 287.76±1.46 N was discovered in the white rice with 49.50% moisture content, while white and black glutinous rice with higher moisture contents had the lowest hardness values.

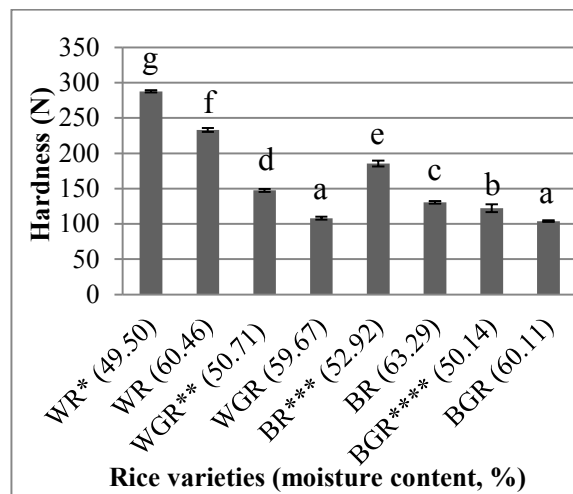


Figure 1. Hardness (N) of vacuum impregnated rice

*WR: white rice, **WGR: white glutinous rice, ***BR: black rice, ****BGR: black glutinous rice

a-g Values followed by different letters within the column are significantly different ($p<0.05$)

Table 2. Physicochemical properties of vacuum impregnated rice

Rice varieties (moisture content, %)	X value (m3 liquid/m3 sample)	γ value (m3/m3 initial sample)	$\epsilon\epsilon$ valuens (%)	ϵr value (%)
WR* (49.50)	0.36±0.04b	0.31±0.02c	0.014±0.056	0.080±0.018ab
WR (60.46)	0.29±0.03b	0.21±0.03b	0.051±0.018	0.175±0.017c
WGR** (50.71)	1.15±0.04d	1.00±0.06e	0.038±0.009	0.099±0.031b
WGR (59.67)	0.79±0.05c	0.80±0.80d	0.034±0.037	0.165±0.059c
BR*** (52.92)	0.26±0.08b	0.25±0.30bc	0.072±0.084	0.126±0.050bc
BR (63.29)	0.28±0.08b	0.25±0.04bc	0.015±0.018	0.117±0.011bc
BGR**** (50.14)	0.28±0.04b	0.26±0.07bc	0.022±0.013	0.022±0.018a
BGR (60.11)	0.14±0.06a	0.10±0.02a	0.036±0.036	0.111±0.036bc

*WR: white rice, **WGR: white glutinous rice, ***BR: black rice, ****BGR: black glutinous rice

a-e Values followed by different letters within the column are significantly different ($p<0.05$)

ns Not significantly different

Figures 2 and 3 display water loss and solid gain of vacuum impregnated rice, respectively. Both studied parameters were significantly affected by different rice varieties and moisture contents examined in this work ($p < 0.05$). All rice treatments had negative values of water loss, indicating

the permeation of external solution into the rice samples during VI processes (Rongkom et al., 2013). From Figure 2, it showed clearly that the white glutinous rice significantly had lower water loss compared to the other rice varieties.

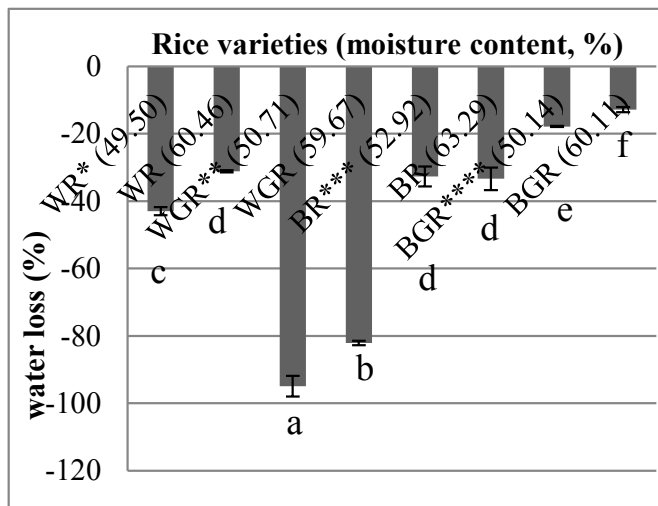


Figure 2. Water loss (%) of vacuum impregnated rice

*WR: white rice, **WGR: white glutinous rice, ***BR: black rice, ****BGR: black glutinous rice

^{a-f} Values followed by different letters within the column are significantly different ($p < 0.05$)

The lowest water loss was found in the white glutinous rice with 50.71% moisture content (a value of $-94.97 \pm 3.06\%$). For solid gain, it was only white rice that had positive values of the variable. The other rice varieties experienced some losses of solid during VI processes. The white rice with 49.50% moisture content had the highest solid gain after the VI process (a value of $2.45 \pm 0.16\%$).

4. Discussions

The predetermined moisture contents of 50 and 60% were chosen because at these moisture contents, the studied rice varieties were cooked well and their texture was not too soft to do impregnation. To achieve these moisture contents, different rice varieties were treated differently (Table 1)

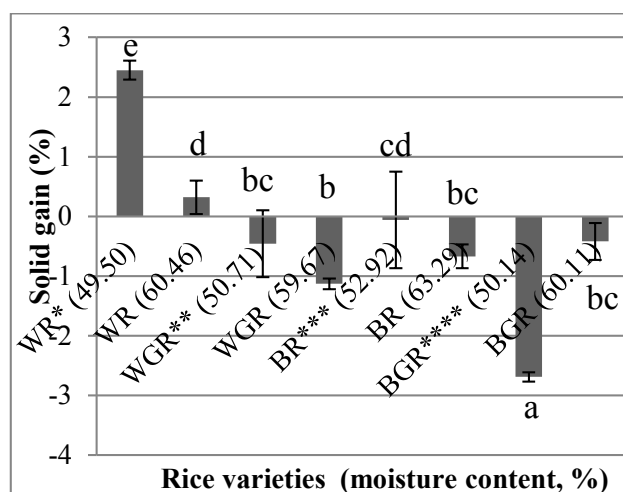


Figure 3. Solid gain (%) of vacuum impregnated rice

*WR: white rice, **WGR: white glutinous rice, ***BR: black rice, ****BGR: black glutinous rice
^{a-e} Values followed by different letters within the column are significantly different ($p < 0.05$) due to different chemical composition of the rice and final moisture content.

4.1 X and γ values of vacuum impregnated rice

X value referred to volumetric fraction of a sample occupied by external liquid and γ value was a sample volume deformation at the end of vacuum impregnation process (Fito et al., 1996; Krasaekoopt and Suthanwong, 2008; Rongkom et al., 2013). The values of both parameters were found to be positive in this study, indicating that external solution was flown into rice kernel during VI processes. The process might, in turn, cause deformation in the rice structure after the treatment. Data also showed that most of X values were slightly higher than the γ values. According to Derossi et al. (2012), this fact showed that impregnation liquid flowing into tissue was faster than the deformation of food structure. The highest X and γ values were determined in white glutinous rice, irrespectively to the moisture content. This result demonstrated that the rice variety that the highest ability to allow

penetration of external liquid, which subsequently caused the highest deformation of the rice structure after the VI treatment.

It was previously reported that X and γ values were affected by structure of food material (porosity, size and shape), vacuum impregnation condition and viscosity of solution (Fito et al., 1996; Rongkom et al., 2013). The important of these factors was due to the fact that phenomena of VI about gas flowing out from tissue, deformation of structure and external liquid flowing into sample tissue were the results of the mentioned factors. Data in Table 2 also exhibited that black rice variety, both glutinous and non-glutinous types, generally had lower X and γ values compared to those of the white rice variety. This finding could be affected by the presence of bran in the rice (a whole rice grain) that might prevent permeation of external solution during VI processing (Billiris et al., 2012). The white rice variety,

which was available as milled rice, might allow an easier penetration or absorption of external solution into their kernel. The texture of the last rice after cooking that was extremely soft and sticky (Bhattacharya, 2011; Lu et al., 2013) could influence deformation of the rice structure, leading to higher γ value.

4.2 ϵ_e and ϵ_r values of vacuum impregnated rice

The ϵ_r value was represented an empty space inside a sample that could be impregnated with VI (external) solution (Rongkom et al., 2013). On the other hand, the ϵ_e value, which was an important parameter of impregnation processing, was known as the volume in sample tissue that could be occupied by VI solution (Krasakoopt and Suthanwong, 2008). Data in Table 2 exhibited that the ϵ_r values were higher than those of the ϵ_e value, except for the black glutinous rice with 50.14% moisture content. This result indicated that there was still some empty space inside the rice kernel that could be occupied by external solution. At higher moisture content within a same rice variety, there were higher ϵ_r value, except for the black rice variety. This finding suggested that initial moisture content of cooked rice affected empty spaces inside the rice kernel. A more detail study with an electron microscope might further confirm this assumption. Statistical analysis for the ϵ_e value revealed that different rice varieties and moisture content did not significantly affect the parameter ($p \geq 0.05$). This finding was similar to the report of Fito et al. (1996) for VI of fruits and mushroom at 50 mbar.

4.3 Hardness of vacuum impregnated rice

Figure 1 disclosed that non-glutinous rice varieties had higher hardness compared to those of glutinous rice types at

similar moisture content. The hardness of vacuum impregnated rice decreased at higher moisture content within the similar rice type. This finding was in an agreement with the report of Horigane et al. (2013) that stated hardness of cooked rice was related to amylose content and moisture content. The texture of cooked rice with higher amylose content was firm, fluffy and had higher hardness. An increase in amylose content led to higher hardness of rice (Lu et al., 2013). The glutinous (waxy) rice variety is lack with amylose content (0-5%) (Bhattacharya, 2011), but it has a high amount of amylopectin (Mee-ngern et al., 2014). Bhattacharya (2011) and Lu et al. (2013) cited that rice with low amylose content was greatly soft and sticky texture. The finding of moisture content in this study was similar to the result of Daomukda et al. (2011), who found out that gelatinisation of starch tended to decrease with decreasing ratio of water to rice. The last study also revealed that texture of cooked rice with water to ratio of 2:1 was harder compared to ratios of 3:1 and 4:1.

4.4 Water loss and solid gain of vacuum impregnated rice

Data of water loss clearly revealed that VI process was a potential treatment to introduce external solution directly into the rice kernel. All of the rice treatments experienced negative values of water loss (Figure 2). The highest water gain was determined in white glutinous rice. Bhattacharya (2011) had stated that water uptake was affected by rice varieties. A study result of Mee-ngern et al. (2014) showed that Sanpathong-1 rice (a white glutinous rice variety) had much more large micro pores, which were easier to be penetrated by water than Khao Dawk Mali 105 and Chainat 1, which were white rice varieties. Porosity of material that affected

water loss had been referred by Rongkom et al. (2013). These researchers reported that pores at different size distribution inside a sample tissue that contained gas was replaced by external solution during a VI treatment. In contrast to the white glutinous rice, black glutinous rice had the lowest water gain after the VI processes (Figure 2). The finding could be affected by the condition of the rice, which was unpolished, whole grain rice (Bhattacharya, 2011). Billiris et al. (2012) identified milling as one of the factors affecting water absorption. Lower degree of milling would lead to a slower rate of water absorption and decreasing rice moisture content. The presence of bran could also prevent water absorption into rice kernels. For solid gain, it referred to addition of solid into sample porous material, which was affected by molecular size of water and solid (Rongkom et al., 2013). Most of rice varieties studied in this research had negative values of solid gain, except for white rice type. This indicated that most of the rice samples experienced solid loss from the kernels during VI treatments. Bhattacharya (2011) also reported the loss of solid during rice cooking. Several factors that affected solid loss were water uptake, age of rice after harvest, cooking time and amylose content (Bhattacharya, 2011). The values of solid gain were generally higher for non-glutinous rice types than those of the glutinous one. This could be due to the lack of amylose content in the last rice variety.

5. Conclusion

It was clearly presented that rice varieties and moisture content of cooked rice significantly affected physicochemical

properties of vacuum impregnated rice ($p < 0.05$), except for effective porosity. White glutinous rice with 50.71% moisture content had a high potential to be further processed with VI. This rice treatment obtained the highest rice volume to be impregnated with external solution and the lowest water loss value. However, the rice structure was greatly deformed after the treatment.

6. Acknowledgement

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