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Research article

Evaluation of final quality of germinated brown rice following steaming and hot-air drying at different temperatures

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Abstract

Importance of the work: Heat treatment factors (steaming and different drying temperatures) can influence the final quality of germinated brown rice.

Objectives: To evaluate the final quality of germinated brown rice (GBR) under steaming and hot air drying at different temperatures.

Materials & Methods: Brown rice was soaked at 40°C for 4 hr before being incubated at 40°C and 90% relative humidity for another 20 hr to make the GBR samples. Then, the GBR was separated into two groups that were subjected to different treatments: steamed drying (S) and non-steamed drying (NSD). The S group consisted of GBR samples that were steamed at 100°C for 10 min before being individually dried at temperatures of 20°C, 40°C, 80°C or 160°C, whereas the NSD GBR samples were dried at these same temperatures without pre-steaming.

Results: Germination increased the plate count of microorganisms to 5.67×10^6 colony forming units (CFU)/g; however; this was reduced during high-temperature drying (2.57×10^3 CFU/g). The yellowness of the NSD increased with increasing drying temperature (from 23.65 to 25.21); however, there was no impact of the yellowness for the S group. The lowest lightness (L*) of the S group was obtained by drying at low temperatures (20°C, 40°C), with significant increases to 58% and 60% after drying at 80°C and 160°C, respectively. It also increased the pasting properties of the NSD and S treatments. Scanning electron microscopy confirmed the gelatinization of the S group at all drying temperatures.

Main finding: GBR was improved through steaming and subsequent drying which also removed moisture from the grain mass to enhance longer-term storage microbial quality.

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Introduction

Brown rice is less popular than milled or white rice, despite being higher in lipids, proteins, and vitamins B1 and B2 (Cho and Lim, 2016). It also has certain drawbacks, such as a longer cooking time and a harder cooked texture due to the bran's fiber content (Heinemann et al., 2005; Patil and Khan, 2011; Chapagai et al., 2017; Mohan et al., 2017). The oil content in the bran reduces its shelf life due to rancidity (Parnsakhorn and Langkapin, 2013). To overcome these disadvantages, germination has been widely used on brown rice to soften its texture and increase its taste, nutritional value and health benefits (Fengfeng et al., 2013).

It is commonly acknowledged that the nutrient contents in GBR could be enhanced by soaking brown rice under optimal conditions. For example, enzymes created during the sprouting process break down proteins and carbohydrates, giving the germinated brown rice a sweet flavor. In addition, it becomes easier to cook since the outer bran layer softens (Hagiwara et al., 2004; Komatsuzaki et al., 2007). Other research has reported that proteins can break down into amino acids, especially glutamic acid, which can be changed into gamma-aminobutyric acid (GABA) via the glutamate decarboxylase enzyme (Zheng et al., 2017). Several studies (Oh and Oh, 2003; Miura et al., 2006; Wu et al., 2013) reported that germinated brown rice had numerous beneficial physiological effects, including antihyperlipidemia, antihypertension and a lower risk of several chronic diseases. Zhang et al. (2014) found that soaking brown rice (the Jing 305 and Guichao 2 varieties) in distilled soaking water at pH 7 and 30°C, followed by germination at 35°C for 36 hr, resulted in the maximum GABA. Specifically, soaking brown rice under appropriate conditions increased the GABA content of the germinated brown rice products. However, in the scientific literature, there is still little information on the heat treatment variables impacting the quality of germinated brown rice. The removal of moisture from the grain mass through steaming and subsequent drying is a procedure reported to enhance GBR quality, maintain nutritional value, quality, and viability and ensure safe storage (Cáceres et al., 2017; Ren et al., 2020). The drying process also refers to the removal of relatively small amounts of moisture and involves simultaneous heat and mass transfer operations (Srisang et al., 2011, 2015; Kiattisak et al., 2013). Furthermore, drying has an effect on rice texture, color and GABA concentration, with latter reported to decrease markedly with increasing drying temperature and time (Cheevitsopon and Noomhorm, 2015). Despite extensive research on the removal of moisture content in GBR under various drying temperatures, data regarding the effects of steaming and subsequent drying on the qualities is very limited.

It is widely accepted that by soaking brown rice under ideal circumstances, the nutritional value of GBR could be increased (Sasagawa et al., 2006; Wu et al., 2013; Zhang et al., 2014; Ren et al., 2020). However, there is little information on the heat treatment parameters that affect the quality of GBR, especially regarding its pasting qualities following thermal treatments. Hence, steaming and subsequent high-temperature drying may have an impact on the pasting qualities of GBR. Thus, the goal of the current study was to compare the effects of steamed drying (S) and non-steamed drying (NSD) on the physicochemical characteristics of GBR by investigating final GBR products for their pasting properties and analyzing scanning electron microscopy (SEM), whiteness, color value and their microbiological condition.

Materials and Methods

Brown rice samples preparation

Low-amylose Khao Dowk Mali 105 (KDML 105) paddy rice, with an average initial moisture content of 12–13% on a wet basis (wb), was provided for this study by the Pathum Thani Rice Research Center in Thailand. The rice was stored in a 5 kg polyethylene bag, kept in the refrigerator at 4°C and was free of rice straw and other foreign objects. The rice samples were taken out of the refrigerator and left at 25°C for 1 d before being shelled using a THU 35A rubber roll sheller (Satake Corp; Hiroshima-ken, Japan) and then graded using a TRG-05B rice grader (Satake Corp; Hiroshima-ken, Japan) to separate the broken kernels. Because of their sensitivity to deterioration, the brown rice samples were prepared a maximum of 1–2 d before testing.

Effects of steaming and drying on physical and chemical characteristics of germinated brown rice

As depicted in Fig. 1, 2 kg of brown rice were soaked in water at 40°C for 4 hr. Then, the soaked rice was kept in plastic containers with lids for a further 20 hr of incubation at 40°C and 90% relative humidity (RH) after being wrapped in filter cloth. To avoid fermentation and off flavors, the brown rice samples were additionally washed in clean water every 4 hr during incubation. The seeds were considered to have germinated when their radicle or germ length reached approximately 1–2 mm.

The post-incubated GBR was divided into two groups: steamed (S) and non-steamed (NSD). The GBR in the first group was mounted on wire netting and heated to 100°C for 10 min in an SA-300VL autoclave (Sturdy apex group; Taipei, Taiwan). The steamed rice samples were taken out and stored for drying. The GBR samples in the second group were not pre-steamed but were exposed to the same drying process. An experimental design series oven drier (WTB; Bender, UK) was utilized to dry the GBR samples in both groups. In the drying process, 1 kg of each non-steamed and steamed germinated brown rice sample with a high moisture content was spread onto 1 mm-thick trays. Separate samples were baked in the hot-air oven at controlled temperatures of 40°C, 80°C, or 160°C. Since a drying temperature of 20°C is below the ambient room temperature, rendering the hot-air oven unusable, drying at such a low temperature was achieved using the incubator at 50% RH and 20°C, with manual stirring. The drying process was stopped when the moisture content of the completed items reached 12±1% wb. After that, it was maintained at room temperature in airtight polyethylene bags to maintain hardness and a constant moisture content. The dried GBR samples were tested for physicochemical parameters 1 wk later.

Physicochemical properties

Moisture content

The conventional oven method was used to determine the moisture content of the rice grain samples (Mathews, 1962). A moisture can was placed in the hot-air oven for 1 hr and kept in a desiccator to cool to ambient temperature after which its weight was determined. Rice grain samples weighing approximately 30 g were placed in separate moisture cans and dried for 16 hr in the hot-air oven at 130°C. Then, the samples were cooled in a desiccator for 45 min before being weighed. The moisture content on a percentage wet basis was estimated using Equation 1:

$$\text{Moisture content} = \frac{(\text{Initial weight - Final weight})}{\text{Initial weight}} \times 100 \qquad (1)$$

The amount of water that must be added at the stage of rapid visco analyzer (RVA) process was calculated using the moisture content of rice flour, which was assessed differently from that of the rice grain using the method of Lees (1971). Briefly, a sample of rice flour (weighing around 5 g) was dried for 16 hr at 105°C in the hot-air oven or until the sample weight remained constant.

Pasting properties

The RVA unit and the associated Thermocline for Windows software version 98 (Model 4D; Newport Scientific; Warriewood, NSW, Australia) were used to analyze the pasting characteristics of samples utilizing the standard 1 measurement profile (ICC Standard Method No. 162), according to Newport (1995)). The viscosity was measured in RVU units. In an RVA canister, a 3 g sample of 12% wb rice flour was dispersed in 25.0 mL of distilled water. A paddle was inserted and used as a stirrer within the canister. The canister with paddle was placed in the instrument. Using the planned heating and cooling cycle, the RVA canister was swirled at 960 revolutions per minute (rpm) for 10 s and then at 160 rpm for the remaining duration. The test is divided into five stages: 1) the addition of water to the starch or flour sample; 2) heating; 3) holding at the maximum temperature; 4) cooling; and 5) a final holding stage. The standard temperature profile stages were: initial temperature set at 50°C; holding time of 1 min at 50°C; heating to 95°C over 3 min 42 s; holding at 95°C for 2 min 30s; cooling to 50°C over 3 min 48 s; and lastly, holding at 50°C for 2 min. The pasting profile was used to measure the peak and trough viscosities as well as the final viscosity, pasting temperature, peak duration, breakdown and setback. The pasting values for each sample were measured for three replicates and expressed as mean ± SD values.

Whiteness and color value

A Kett digital whiteness meter (Model C-300; Tokyo, Japan) was used to test the whiteness of each germinated brown rice sample. The meter was calibrated to 88.1% whiteness against standard white before being used for measurements.

The color of all samples was measured using a color difference meter (Model JC801; Color Techno System Co.; Tokyo, Japan). The lightness (L^*), redness (a^*) and yellowness (b^*) of the samples were used to calculate the color values, which were then averaged to represent the various color differences caused by the various treatments. A standard white plate with L^*, a^* and b^* values of 98.11, 0.11 and 0.08, respectively, was used to calibrate the color meter before applying the procedure. The color value for each sample was measured for three replicates and expressed as a mean ± SD value.

Microbiological analysis

The aerobic plate counts (APC) determined using the decimal dilution method from the germinated brown rice product were cultured for 48 hr at 35°C using a standard medium and expressed in colony forming units per gram (Association of Official Analytical Chemists, 2000). The microbiological quality for each sample was measured for three replicates and expressed as a mean ± SD value.

Scanning electron microscopy

SEM (S-2500; Hitachi Ltd; Chiyoda, Tokyo) was used to observe changes in the microstructure of the rice samples. Each rice sample was manually broken along its cross-sectional axis and glued onto a bronze cylinder. To prevent moisture loss during the photographic process, it was then coated with platinum-palladium for 4 min using a sputter-coater (Model: E-102; Hitachi Ltd; Chiyoda, Tokyo, Japan).

Statistical analysis

Each GBR steaming experiment and the subsequent drying process was conducted in triplicate. Data were expressed as mean ± SD values. The data obtained from each experimental condition were subjected to one-way analysis of variance and Duncan's multiple range test was used to determine significant differences at the $p < 0.05$.

Results and Discussion

Effects of steaming and drying treatments at various temperatures on germinated brown rice moisture content

In the experiments, fresh GBR was readily affected by microbial invasion at a moisture content higher than 30% wb. The GBR samples (both steamed and non-steamed) were dried in a hot-air oven to a safe storage dryness level of 13–14% wb (Chungcharoen et al., 2015) at drying temperatures of 20°C, 40°C, 80°C, and 160°C. The drying times for the non-steamed (NSD) and steamed (S) GBR samples were in the range 12–20 hr and 15–24 hr, respectively. The steaming treatment retarded the removal of moisture from the rice kernels at all drying temperatures studied. Evaporation of moisture from the grains during drying was slowed because the grain hydrated during soaking and the starch gelatinizes during steaming covered up the cracks inherently present in the kernels.

The correlations between the moisture removed from germinated brown rice at various drying temperatures and drying times are depicted in Fig. 2. It was discovered that a higher rate of moisture removal was proportional to an increase in drying temperature; it required 1 d at low temperature (20°C) for the moisture content to be lower than 14% wb; after which it was safe for long-term storage (Jittanit et al., 2010), but a mere 12 min was required at a drying temperature of 160°C.

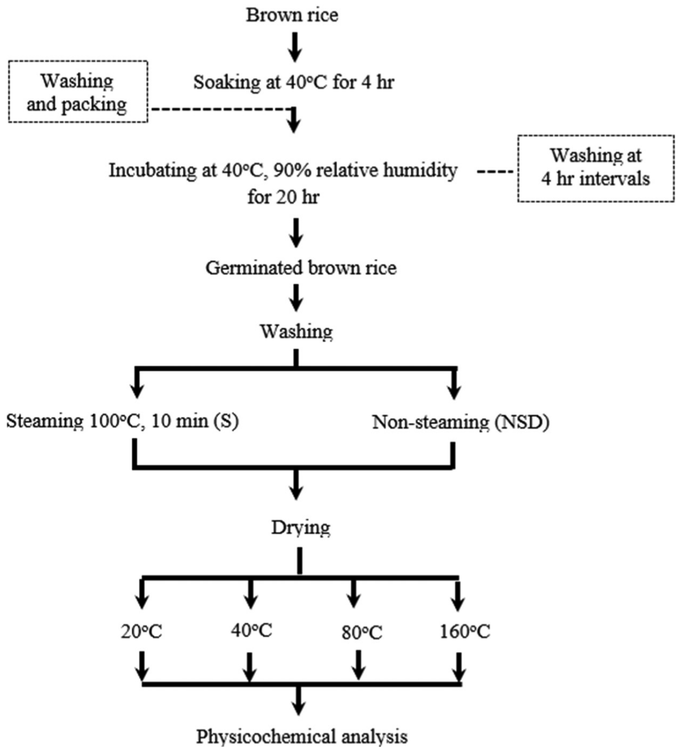

Fig. 1 Diagram of experimental setup for determining effects of steaming and drying treatment on germinated brown rice quality

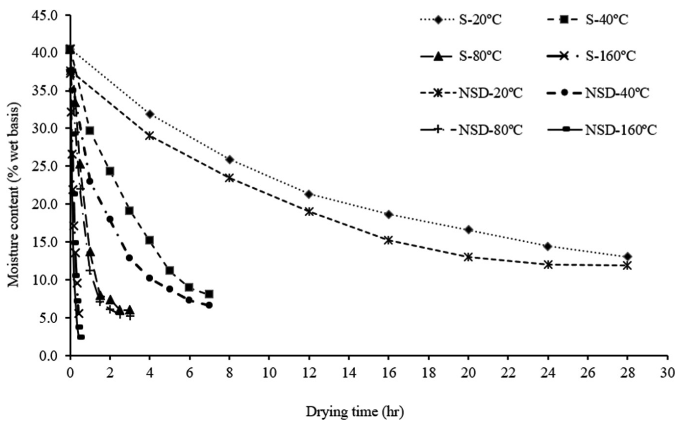

Fig. 2 Moisture content of germinated brown rice samples subjected to different drying temperature (20°C, 40°C, 80°C, 160°C) across drying time 0–30 hrs; where S = steamed drying and NSD = non-steamed drying

However, brands of dry germinated brown rice available in the market exhibited a common problem that the brown rice absorbed water in the germination process and the swollen germinated rice cracked in the drying process. It was discovered that a moderate steaming time of 10 min at 100°C was more suitable for improving the appearance and minimizing grain deformation.

Effects of steaming and drying at different temperatures on physical and chemical characteristics of germinated brown rice

Pasting properties

Table 1 and Figs. 3 and 4 show the pasting properties of the NSD and S treatments. The observed pasting properties reflected the complex interactions of starch and water as affected by temperature and time. According to the findings, increasing the drying temperature in the range 40–160°C increased the pasting quality.

Increased viscosity was observed during the heating process. The pasting temperature (PT) is the temperature at which the viscosity of the starch begins to rise, since the viscosity only begins to increase once the starch granules are completely gelatinized. According to Table 1, the PT of brown rice (71.23 ± 1.94°C) and slightly increased (72–77°C) in the NSD treated samples, whereas the S treatments and drying at low temperatures (20°C, 40°C, 80°C) resulted in PT values of 82.67±4.45°C, 55.79±3.31°C, 86.70±3.13°C and 78.88±2.96°C, respectively. Mohapatra and Bal (2003) reported that the gelatinization temperature range for powdered milled rice samples was 73–77°C. The PT is often greater than the gelatinization temperature; thus these results indicated that the NSD and S samples had been completely gelatinized.

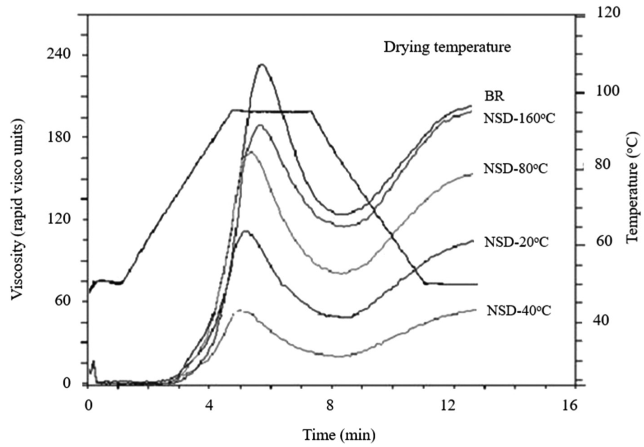

Fig. 3 Pasting properties of germinated brown rice flour with non-steamed drying (NSD) at different drying temperature (20°C, 40°C, 80°C, 160°C) across 0–16 hrs drying time; where BR = brown rice

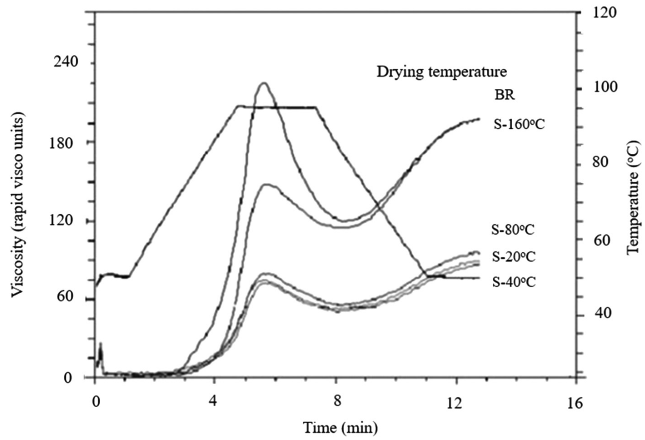

Fig. 4 Pasting properties of germinated brown rice flour with steamed drying (S) at different drying temperatures (20°C, 40°C, 80°C, 160°C) across 0–16 hrs drying time; where BR = brown rice

Table 1 Pasting properties of post-drying germinated brown rice at various steaming temperatures

Treatment	Peak viscosity (RVU)	Trough (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Setback (RVU)	Peak time (min)	Pasting temperature (°C)
BR	229.26±11.46[a]	114.85±7.20[a]	114.42±13.35[a]	191.60±10.49[b]	76.75±4.53[b]	5.59±0.18[b]	71.23±1.94[e]
Non-steamed							
NSD-20°C	103.65±4.93[e]	45.47±2.20[d]	58.50±2.62[d]	100.58±3.74[d]	55.29±1.54[d]	5.26±0.06[d]	73.71±1.08[de]
NSD-40°C	56.30±1.94[h]	20.34±0.54[e]	35.87±1.51[e]	55.52±1.07[g]	35.08±1.17[f]	5.01±0.03[e]	73.45±2.44[de]
NSD-80°C	162.96±4.77[c]	79.21±2.10[b]	83.65±3.55[b]	152.43±2.51[c]	72.80±1.00[c]	5.45±0.07[c]	72.82±1.99[e]
NSD-160°C	188.83±3.86[b]	114.02±5.18[a]	75.39±2.85[c]	195.68±7.36[ab]	82.91±2.35[a]	5.62±0.11[b]	76.73±1.17[cd]
Steamed (100°C, 10 min)							
S-20°C	77.24±3.55[f]	54.05±1.22[c]	25.01±2.16[f]	94.82±2.94[de]	41.19±2.68[e]	5.71±0.13[ab]	82.67±4.45[b]
S-40°C	79.09±4.73[f]	54.48±3.99[c]	24.26±1.21[f]	93.40±5.14[e]	41.39±4.66[e]	5.67±0.07[b]	55.79±3.31[f]
S-80°C	69.07±2.28[g]	48.06±1.83[d]	20.88±0.72[f]	84.90±2.05[f]	35.77±1.34[f]	5.67±0.11[b]	86.70±3.13[a]
S-160°C	148.11±4.64[d]	115.59±3.39[a]	33.57±2.42[e]	200.47±4.88[a]	84.61±1.45[a]	5.83±0.04[a]	78.88±2.96[c]

BR = brown rice; NSD = non-steamed drying; S = steamed drying; RVU = rapid visco units.

Data are shown as mean values ± SD of three independent experiments ($n = 3$).

Mean (± SD) values in the same column superscripted with different lowercase letters are significantly ($p < 0.05$) different.

The peak GBR viscosity increased with rising drying temperature, in the range 56–188 RVU. When dried at the same temperature, the peak viscosity of the NSD-treated GBR was greater than for the S-treated GBR. For example, drying at 80°C with NSD produced a peak viscosity of 162.9±64.77 RVU, whereas for the S treatments and drying at the same temperature, the peak viscosity was 69.0±72.28 RVU. This pattern was similar for drying at temperatures of 20°C and 160°C. Because the brown rice starch granules in NSD-treated germinated drying at 20°C, 80°C and 160°C were neither destroyed or denatured by heat, they remained intact with a high peak viscosity and the ability to swell considerably. Particularly at high temperatures, drying occurred quickly and had little impact on the grain structure. The pasting quality was dependent on the stiffness of the starch granules, which impacted granule swelling. The peak viscosity for the NSD treatment and drying at 40°C was lower (56.30±1.94 RVU) compared to the other drying temperatures (20°C, 80°C, 160°C) in the range 103–188 RVU. However, there were significant differences for the S-treated GBR at low temperatures, with values of 77.24±3.55 RVU, 79.09±4.73 RVU and 69.07±2.28 RVU for 20°C, 40°C and 80°C, respectively, which rapidly increased to 148.11±4.64 RVU after drying at 160°C; however this was less than the BR viscosity because the BR starch granules were not denatured or destroyed by heat. A higher RVA peak viscosity in rice granules results in a higher starch granule stiffness (Horigane et al., 2000). Apart from the drying phases, amylose and amylopectin molecules in starch granules loosened during gelatinization (at temperatures greater than 70°C for rice flour) according to Jaisut et al. (2008).

Germination affected the pasting qualities of brown rice flour, as shown in Table 1 and Figs. 3 and 4, with the GBR flour having a lower peak viscosity than the BR flour. The decrease in peak viscosity was most likely caused by starch hydrolysis during the germination process and increased amylase activity in the germinated grains (Moongngarm and Saetung, 2010). Peak viscosity has been reported to be correlated with the starch water binding capacity, which occurs at the equilibrium point between swelling, causing increases in viscosity, rupturing and realignment, which in turn decrease the viscosity (Sanni et al., 2001). The differences in peak viscosity values could be attributed to the degree of gelatinization and the development of amylose-lipid complexes. The presence of amylose-lipid complex inhibits the gelatinization of starch granules (Charles et al., 2005). Lipids may affect the diffusion of water into the starch granules and their presences on starch granules can retard gelatinization. Li et al. (2016) reported that defatted starch resulted in a decreased gelatinization temperature. The degree of gelatinization is affected by a variety of parameters, including the initial moisture content and drying temperature (Jaisut et al., 2008). In GBS rice with sufficient moisture content, the drying temperature had a substantial impact on the level of gelatinization (Taechapairoj et al., 2004). The steaming treatment gelatinized the starch granules and increased the connections between starch granules more than in the non-steam treatment, as evidenced by the fact that the heat treatment reached deeper into the rice grains after steaming. As shown in the SEM images (Fig. 5), the interior structure of the NSD-treated samples had more hollows than the S treated samples.

In addition, changes were observed in the pasting properties of trough or minimum viscosity of the NSD- and S-treated samples, as shown in Table 1. As previously stated, the steaming treatment influenced rice starch characteristics and lowered the pasting viscosity. However, for drying at high temperatures,

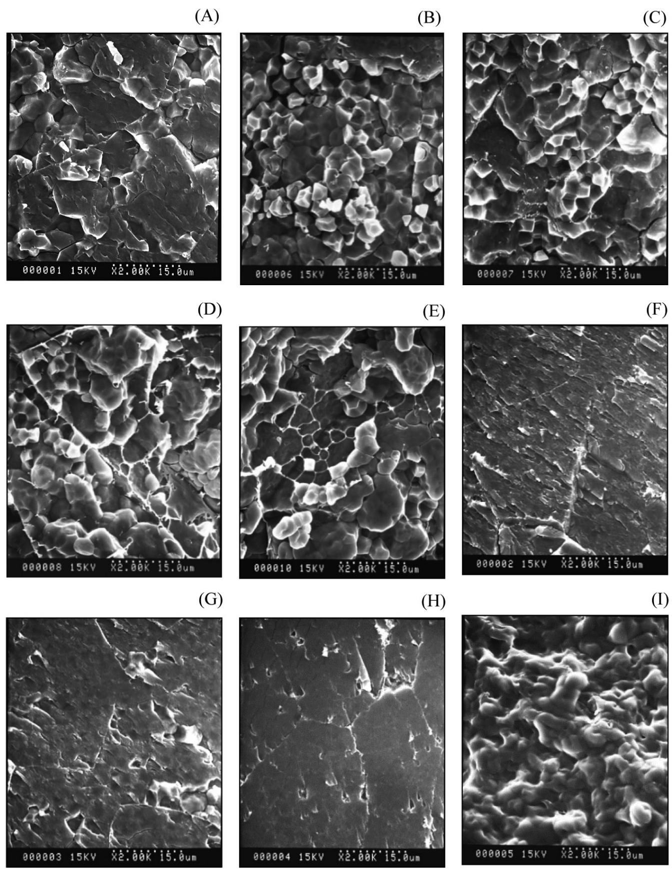

Fig. 5 Scanning electron images of: (A) Brown rice (KDML 105); (B) non-steamed brown rice (NSD) dried at 20°C; (C) NSD dried at 40°C; (D) NSD dried at 80°C; (E) NSD dried at 160°C; (F) steam-dried rice (S) dried at 20°C; (G) S dried at 40°C; (H) S dried at 80°C; (I) S dried at 160°C

substantial variations in trough values were recorded. The S treatments had greater pasting temperatures than for NSD when dried at the same temperature. Based on these findings, it is plausible that the higher pasting temperatures in the S treatments were caused by gelatinization of the treated starch granules during steaming and drying (Jaisut et al., 2008), which inhibited water penetration, which increased the temperature required for starch swelling (Kaur and Singh, 2000).

The breakdown viscosity values of the NSD and S treatments were much lower than for brown rice (114.42±13.35 RVU), even though the NSD treatments resulted in an increase in the breakdown value after increasing the drying temperature. These results were similar for the S treatments, where the breakdown values were lower, resulting in the lowest breakdown viscosity for the S treatment drying temperature of 80°C. These results of the decrease in breakdown viscosity demonstrated that steaming and drying considerably improved granule stiffness (Jaisut et al., 2008). The gelatinization of starch that occurred after steaming and drying assisted in joining cracks within the kernels, resulting in a stronger structure and a decrease in the breakdown viscosity, resulting in only a slight drop in the final viscosity for the S treatments dried at low temperatures of 20°C, 40°C and 80°C, with values of 94.8±22.94 RVU, 93.40±5.14 RVU and 84.90±2.05 RVU, respectively, compared to the considerable rise at 160°C to 200.47±4.88 RVU. The final viscosity increased with the higher drying temperatures and reached its highest value of 195.68±7.36 RVU at 160°C, which contradicted the NSD trend.

The recrystallization of gelatinized starch is referred to as the setback viscosity and also known as retrogradation. According to the findings, the setback viscosity was altered by the steaming and drying temperatures in such a way that increasing the drying temperature increased the setback viscosity. At high temperatures, the time required to remove moisture was short, whereas at low temperatures, a longer time was required, resulting in higher setback viscosities in both the S and NSD treatments. However, these findings contradicted the findings of Jaisut et al. (2008), who observed that increasing the drying temperature resulted in a decreased setback. There were no significant differences in the values for the peak time of the S treatments at various temperatures (20–160°C) at 5.7 min, whereas for the NSD treatments, there were significant differences with different drying temperatures.

Color (L,a*,b*) and whiteness*

Table 2 shows the color parameters (L^*, a^*, b^*) of the S and NSD treatments at various drying temperatures (20°C, 40°C, 80°C, 160°C) compared to the same color parameters in the BR sample. These results showed that L^* varied between 61.25 and 65.37 for the NSD treatments and between 55.77 and 60.31 for the S treatments. Overall, compared to brown rice, the L^* values of GBR declined with drying temperature, resulting in a darker color of the dried GBR. The yellowness (b^*) of the NSD-germinated brown rice increased with increasing drying temperature (from 23.65 to 25.21). At all temperatures, there was no change in the yellowness value, which was in the range 26–27 for the S samples. Because greater drying temperatures resulted in increased yellowness, the severity of drying was clearly connected with yellowness change. However, although the color of the rice grain changed after drying the GBR, but there were negligible differences in the redness value (a^*).

The S-treated GBS dried at 20°C and 40°C had the lowest lightness (L^*) in the range 55.77–56.41, which significantly decreased to 58.80 and 60.31 after drying at 80°C and 160°C, respectively. However, the data in Table 2 show that there was no clear difference in lightness among the NSD treatments.

Table 2 Physical properties of germinated brown rice under various temperatures for steamed drying (SD) and non-steamed drying (NSD)

Treatment	Color value			Whiteness	Colony forming
	L^*	a^*	b^*	(%)	units/g
BR	65.76±0.68[a]	2.04±0.01[c]	24.97±0.01[d]	22.30±0.01[a]	1.01×10^4
NSD-20°C	63.08±0.41[b]	2.98±0.15[a]	23.65±0.15[e]	22.80±0.02[a]	1.53×10^6
NSD-40°C	61.25±0.95[cd]	2.72±0.21[ab]	23.83±0.25[e]	21.30±0.04[b]	3.97×10^5
NSD-80°C	65.83±0.44[a]	2.69±0.13[ab]	25.06±0.04[d]	21.00±0.01[c]	7.43×10^4
NSD-160°C	62.37±0.37[bc]	2.58±0.27[b]	25.21±0.19[d]	20.80±0.06[d]	2.97×10^4
S-20°C	55.77±1.28[f]	2.73±0.27[ab]	26.25±0.27[c]	16.40±0.04[g]	4.17×10^5
S-40°C	56.41±0.48[f]	2.88±0.30[ab]	27.54±0.29[a]	16.13±0.03[h]	1.81×10^5
S-80°C	58.80±0.84[e]	2.88±0.12[ab]	26.84±0.43[b]	17.70±0.01[f]	1.41×10^4
S-160°C	60.31±0.45[d]	2.90±0.20[ab]	26.65±0.50[bc]	19.53±0.06[e]	4.53×10^3

BR = brown rice; RVU = rapid visco units

Data are shown as mean values ± SD of three independent experiments ($n = 3$).

Mean (± SD) in each column superscripted with different lowercase letters are significantly ($p < 0.05$) different.

Based on these findings, it could be concluded that the large yellowness effect on the S samples was most likely due to color change brought about by non-enzymatic browning or the Maillard reaction, as well as the transfer of yellow pigment from the bran to the endosperm during brown rice soaking and steaming (Lamberts, 2006; Panchan and Naivikul, 2009; Yamirudeng et al., 2022). Palamanit et al. (2019) found that color values altered depending on the convective drying conditions, with an instant increase in temperature for paddy accelerating the Maillard reaction and the transition of color substances from the rice husk and rice bran to the endosperm, causing discoloration. Not only the heating temperature, but also the heating duration induced an increase in the yellowness of rice samples. Drying brown rice at 160°C produced a much greater yellowness value than at 80°C because high temperature drying only required a short period in contrast to the longer time required at low temperatures to achieve sufficient moisture reduction.

According to Table 2, the whiteness values of GBR decreased with drying temperature compared to brown rice, because the increase in the temperature accelerated the rate of the Maillard reaction and produced a golden yellow hue in the GBR (Shen et al., 2021). The whiteness value of BR was 22.30 ± 0.01, which reduced significantly to16–20 following the GBR steaming treatment. The whiteness of the brown rice decreased more due to starch rearrangement in the rice endosperm and translocation of color from the rice bran, which has no insulation from the rice husk during heating (Inprasit, 2001).

Microbiological quality

According to Prokopowich and Blank (1991), soaking seeds in tap water overnight resulted in a 10-fold increase in aerobic plate counts (APCs) due to favorable sprouting conditions (temperature, pH, duration and moisture content). The APCs increased to 5.67×10^6 CFU/g during the GBR preparation process, which involved soaking the brown rice grains in water at 40°C for 4 hr and then incubating at the same temperature for 20 hr. Following the NSD treatment, the APCs reduced with increased temperature drying from 5.67×10^6 CFU/g to 1.53×10^5, 3.97×10^5, 7.43×10^4 and 2.57×10^3 CFU/g at 20°C, 40°C, 80°C and 160°C, respectively. However, the APC was lower in the S treatment than in the NSD treatment (Table 2). As previously stated, the S treatment could be used to reduce microorganisms (Komatsuzaki et al., 2007). Numerous studies have suggested that, in addition to steaming, other methods of microbe eradication include electrochemical treatment (Feng et al., 2004), high pressure treatment of rice (Sasagawa et al., 2006) and ultraviolet irradiation (Suzuki and Maekawa, 1999).

Results from scanning electron microscopy

The SEM micrographs of the GBR starch granules with steamed drying (S) and non-steamed drying (NSD) at different drying temperatures (20°C, 40°C, 80°C, 160°C) are shown in Figs. 5B–5I. The characteristics of the reference starch granules of brown rice are not clearly displayed in Fig. 5A and appear as irregular polygonal forms. At low temperature drying, the properties of starch granules appeared to be irregular polygons for all NSD treatments. Therefore, the granules shapes changed after the brown rice had germinated following both non-steam and steam treatments (Yamirudeng et al., 2022). As illustrated in Figs. 5F–5I, there was clear starch gelatinization in the S samples after drying at various drying temperatures, resulting in an uneven particle surface and severe adhesion. According to the findings, some starch granules lost their structure, while others had a less strongly defined polyhedral shape. The internal spaces of the NSD-treated samples were also hollower than those of the S-treated samples, which developed only a small, circular hollow when dried at the same temperature.

Conclusions

The goal of this study was to determine how different drying temperatures (20°C, 40°C, 80°C, 160°C) affected the physicochemical parameters of germinated brown rice (GBR) after steamed drying (S) and non-steamed drying (NSD). The findings revealed that the drying temperature influenced the physicochemical properties of the final germinated brown rice products. A temperature increase had no effect on the b^* values with the S treatments, whereas a higher drying temperature enhanced the b^* values with NSD. The influence of lightness (L^*) and whiteness was particularly evident with NSD and S. However, it had no effect on the quality of redness (a^*). Steaming and high drying temperatures changed the microstructure of the GBR, confirming gelatinization of the S group at all drying temperatures. GBR's pasting properties were impacted by the steaming and drying temperatures. The high drying temperature increased the pasting properties and decreased the microorganism concentration compared to fresh GBR. The results of this study suggested that steaming and then drying could enhance the qualities of GBR.

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