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Original Article

Effects of drying temperatures on physicochemical properties of germinated brown rice

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Abstract

This research has investigated the effects of varying drying temperatures on the physicochemical properties of germinated brown rice (GBR). The GBR samples were prepared in accordance with the prior research findings by which brown rice was soaked at 40 °C for 4 hrs prior to incubation at 40 °C and 90%RH for another 20 hrs. The resulting germinated brown rice was then divided into two groups and subjected to two different treatments: the steamed drying (SDR) and non-steamed drying (NSD) groups. The SDR group refers to the GBR samples steamed at 100 °C for 10 min prior to individually drying at temperatures of 20, 40, 80, and 160 °C, while the NSD group consists of the rice samples dried at the same temperatures without pre-steaming. The physicochemical properties of the GBR samples were subsequently analyzed to identify the optimal treatment condition. The findings revealed that the drying temperatures influenced the physicochemical properties of both GBR groups. The apparent hardness, water absorption and free fatty acids of both GBR groups were lower than those of the non-germinated brown rice, whereas their total lipids were higher. Besides, the higher drying temperatures had an adverse effect on the GABA content.

Keywords: brown rice, germination, drying, physicochemical properties, GABA

1. Introduction

Despite richer in fats, proteins, vitamins B_1 and B_2, brown rice is less preferred vis-à-vis milled or white rice due to the former's faint aroma, cooking inconvenience and difficulty of digestion. To overcome these disadvantages, germination has thus been commonly applied to brown rice to soften its texture and thereby, unlike ordinary brown rice, makes it possible to cook the germinated brown rice (GBR) using a conventional rice cooker (Watanabe *et al*., 2004).

In the germination process, normal brown rice is soaked for 3 hrs and retained under a suitable condition for 21 hrs to germinate rice embryos and induce the subsequent changes in the physicochemical properties, particularly in the content of gamma-aminobutyric acid (GABA) (Patil & Khan, 2011). Once soaked, glutamate decarboxylase (GAD) in brown rice is activated and it converts glutamic acid into GABA. According to Komatsuzaki *et al*. (2003), glutamic acid is an amino acid present in brown rice as stored proteins and is transformed into a transportation form of amide. In addition, Shinmura *et al*. (2007) and Zhang *et al.* (2014) documented that the soaking of brown rice in 20-40 °C water promoted the GABA quantity. On physical wellness, extensive research studies revealed that a continuous intake of germinated brown rice promotes brain functions, relieves constipation, prevents colon cancer, regulate blood sugar levels, lowers blood pressure and reduces the risks of heart diseases (Hayakawa *et al*., 2004; Imam *et al*., 2014; Jakobs *et al*., 1993; Kawabata *et al*., 1999; Mori *et al*., 1999; Zhang *et al*., 2010).

During germination, enzymes in the brown rice are catalyzed and subsequently induce a transformation of high molecular constituents, i.e. starch, proteins and hemi-

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celluloses, into those of low molecules. In the process of transformation, the physiochemical properties of the grains would undergo numerous changes, including the increase in the quantities of α and β amylases and a partial degradation in the endosperm (Dewar *et al*., 1997). According to Ayernor and Ocloo (2007), α-amylase in rice plays a significant role in the hydrolytic breakdown of reserve starch in endosperm tissues during germination, thereby contributing to a more rapid and complete degradation of the starch to fermentable sugar. Nevertheless, the germination process inevitably increases in the moisture content of the grains to approximately 35%, liberates nutrients from the grains, and provides extremely favorable temperature and humidity conditions for microbes. To address, the process of steaming and subsequent drying should thus be applied to reduce the moisture content and hence prolong the storage life of the final products. According to Gariboldi (1974) and Saikusa *et al*. (1994), the moisture content for safe storage of germinated brown rice is 13-14% (w.b.).

Steaming and subsequent drying is a process to improve the quality of GBR and expel moisture from the grain mass to preserve nutritive value, quality and viability and the safe storage. The drying process also refers to the removal of relatively small amounts of moisture and involves the simultaneous heat and mass transfer operations. Watanabe *et al*. (2004) nevertheless reported a near-complete decomposition of GABA for both brown rice and germinated brown rice at a baking temperature of 200 °C. Drying also affects the rice texture and color as the gelatinization temperatures are raised (Cheevitsopon & Noomhorm, 2015). Thus, it is necessary to compare the quality at different drying temperature. Despite extensive research on the removal of moisture content in GBR under various drying temperatures, data with regard to the effects of drying temperatures on the GABA content is very limited.

It is commonly acknowledged that the GABA content in GBR could be enhanced by soaking brown rice under optimal conditions. Nonetheless, knowledge on the heat treatment factors that influence the quality of GBR is limited, particularly that related to the GABA content after thermal treatments. Hence, steaming and subsequent drying at high temperature may decrease a GABA content in GBR. This current research has thus attempted to determine the effects of steamed drying (SDR) and non-steamed drying (NSD) treatments on the physicochemical properties of GBR by examining the GABA content, hardness, whiteness, water absorption, total lipids and free fatty acids in the final GBR products.

2. Materials and Methods

2.1 Brown rice samples preparation

This research used low-amylose Khao Dowk Mali 105 (KDML 105) paddy rice from Thailand's Pathum Thani Rice Research Center, whose average initial moisture content was 12±1% (wet basis). The paddy was free from straws and foreign materials, retained in a 5 kg polyethylene bag and refrigerated at 4±2 °C. Prior to the experiment, the rice samples were removed from the refrigerator and left at 25±2 °C for 1 day before shelling with the THU 35A rubber roll sheller and subsequently graded with the TRG-05B rice grader to sort out the broken kernels. Due to their susceptibility to deterioration, the preparation of brown rice samples was carried out one or two days prior to the experiments.

2.2 Germination procedure

Prior research on germination has revealed that soaking brown rice in warm water for 24 hrs independently induced lower bud growth relative to the combined practice of soaking and subsequent incubation. This current research has thus utilized the combined practice (i.e. soaking and incubation) to achieve a higher level of GABA content.

As illustrated in Figure 1, approximately 2 kg of the brown rice was soaked in water at 40 °C for 4 hrs. The soaked rice was then wrapped in filter clothes and retained in lidded plastic boxes for subsequent incubation at 40 °C and 90%RH for another 20 hrs. During the incubation, the brown rice samples were also washed with clean water every 4 hrs to prevent fermentation and off-flavor. This treatment condition has been found to contribute to the high GABA contents in the resulting germinated rice grains. The post-incubated germinated brown rice (GBR) samples were then subjected to steaming and various drying temperatures before the changes in their physicochemical properties as a result of differing heat treatments were determined.

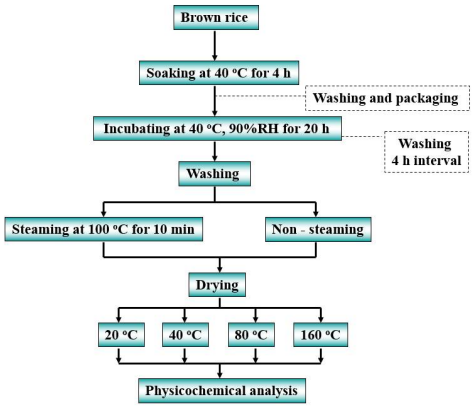

Figure 1. Experimental schematic diagram of how to determine the effects of steaming and drying treatment on GBR quality.

2.3 Effects of steaming and drying treatment on the physicochemical properties of GBR

The post-incubated GBR was divided in two groups: the steamed and non-steamed groups. In the first group, the GBR was placed on wire netting and steamed in the SA-300VL autoclave at 100 °C for 10 min. The steamed rice samples were removed and retained for the subsequent drying process. In the second group, the GBR samples underwent no pre-steaming but were subjected to the same drying process. The ED series oven dryer was deployed to dry both groups of GBR samples. The experimental drying temperatures were of 20 °C, 40 °C, 80 °C, and 160 °C and the effects of the various drying temperatures on the physicochemical properties of GBR were determined.

In the drying process, both non-steamed and steamed germinated brown rice samples with high moisture content were spread onto 1-mm-thick trays and baked in the hot air oven at the controlled temperatures of 40 °C, 80 °C, and 160 °C individually. Nevertheless, since the drying temperature of 20 °C is below the ambient room temperature, rendering the hot air oven unusable, the drying at such a low temperature was achieved by the use of the incubator, in which the humidity and inner temperature were controlled at 50%RH and 20 °C, with manual stirring. The drying process was terminated upon the moisture content in the final products reaching 12±1% (wet basis). The dried GBR samples were then retained in airtight polyethylene (PE) bags at room temperature for moisture equilibration and hardness stabilization (Kimura, 1991) prior to further analysis of their physicochemical properties two weeks later.

2.4 Physicochemical properties

2.4.1 Preparation of flour from germinated brown rice

In determination of total lipids and free fatty acids the dried GBR samples were lyophilized and ground into flour using the ZM 100 ultra-centrifugal mill prior to passing through a 100-mesh sieve. Nonetheless, the practice of lyophilizing and grounding using an ultra-centrifugal mill induced a rapid increase in temperature and thereby adversely affects the nutritive value of GBR. Thus, for the analysis of GABA, a conventional manual stone mortar was utilized to grind the rice with the subsequent powder sieved (100 meshes) and retained in a lidded container at 4 °C for further analysis.

2.4.2 Physicochemical analysis methods

Moisture content: The moisture content of GBR samples was determined using the standard oven method (Methews, 1962) by which 30 g each of the whole-grain GBR samples were individually filled into moisture can and baked in a hot air oven at 130 °C for 16 hrs. On the other hand, the moisture content of GBR flour was estimated using a procedure introduced by Lee (1971), by which 5 g each of the rice flour samples were filled into moisture can and baked in the hot air oven at 105 °C for 16 hrs when the samples reached a constant weight.

Hardness: In this research, the hardness of cooked rice was measured in accordance with the calculated water method (Banjong, 1986; Juliano, 1985). In the measurement, 25 g of GBR samples with predetermined amount of distilled water were filled into 100 ml beakers which were subsequently placed in a cooker filled with 400 ml water. The cooked rice hardness was measured by back extrusion test using LLOYD's LRX plus texture analyzer, modified from a small-sample back extrusion test (Reyes and Jindal, 1990). The average bio-yield point value was expressed as the hardness of GBR in Newton (N).

Water absorption: To determine the water absorption, this research has utilized a modified version of the method proposed by Sabularse *et al*. (1991), by which 2 g of GBR samples were mixed with 20 ml distilled water in a test tube capped with a cotton plug. The test tube was then placed in a thermostatically controlled water bath preheated to the rice cooking temperatures of 97-99 °C. The rice samples were cooked for the minimum cooking time in the water bath and then cooled by iced water. Excess water was then drained out and the test tube retained upside down for 1 h prior to weighing. The water absorption was calculated based on increase in weight and expressed as gram of water per gram of rice (g water/ g rice).

Total lipids and free fatty acids: Total lipids were determined using a modified version of the method in Zhongkai *et al*. (2003), by which 3 g dried GBR flour was mixed with 150 ml petroleum ether and extracted using soxtherm multistat (Model SX PC, Gerhardt, UK). The solvent in the flask was evaporated and then dried in an oven at 105 °C until the weight became constant. The post-extraction weight increase was estimated and total lipids were expressed as the percentage of dried rice flour. Meanwhile, the free fatty acids content was determined by the titration method. Residue in extraction flash was dissolved with 50 mL of 0.04% alcohol-phenolphthalein solution and titrated with 0.0178 N potassium solution (KOH) using phenolphthalein as indicator until a faint pink color persisted for 1 min before calculating the percentage of free fatty acid as oleic acid by Equation 1 (Associate of Official Analytical Chemists, 1995).

$$Free\ fatty\ acid\ (\%) = \frac{KOH\ volume(ml)\ x\ Normality\ of\ KOH\ (0.0178)\ x\ 2.82}{Weight\ of\ sample\ of\ oil\ (g)} \quad (1)$$

GABA content: This research has investigated and compared the GABA contents contained in the embryo (germ) part, the endosperm part and the whole grain (Figure 2). Since the highest GABA content in the rice germ has been extensively documented, this current research has thus deliberately focused on the GABA content in the endosperm part. In the experiments, each grain of GBR (i.e. the whole grain) was divided in four equal sections, consisting of one section and three sections of the embryo and endosperm parts, respectively (Figure 2). The division was terminated once the cumulative weight for the three sections belonging to the endosperm part individually reached 5 g. The cut samples were subsequently pulverized into rice flour using a manual stone mortar before passing through a 100-mesh sieve for 3 g of finer rice flour. The rice flour samples were retained in vacuum-sealed polyethylene bags and refrigerated at 4 °C for the subsequent estimation of the GABA content.

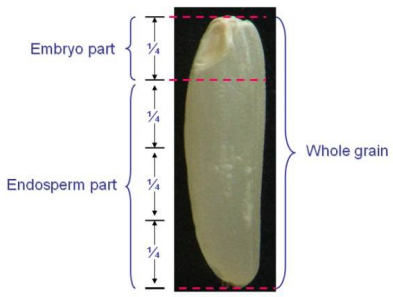

Figure 2. Photograph image of a whole grain rice kernel.

Extraction method: In this research, the extraction method is a modified version of Tian *et al*. (2005), in which 2.5 g of each rice flour sample and 25 ml of 80% (v/v) ethanol were mixed in screw test tubes and centrifuged at 8000 rpm under a low temperature condition (4 °C) for 10 min. The supernatant was then filtered with filter No. 2 and retained in a 50 ml beaker. Another 25 ml of 80% (v/v) ethanol was added into the same screw test tube and extracted in a similar manner with the resulting supernatant collected. The final supernatant was evaporated in a vacuum dryer at 40 °C to dryness prior to further dissolving in 3 ml distilled water.

Spectrophotometer method: In this research, the γ-aminobutyric acid (GABA) determination procedure is a modified version of Kitaoka and Nakano (1959), in which 0.1-0.3 ml of the extracted solution was thoroughly mixed with 0.2 ml of 0.2 M borate buffer and 1.0 ml of 6% phenol were added. For the standard GABA solution (0.1- 0.3 ml) was added to test tubes (18x120 mm) together with 0.2 ml of borate buffer and 1.0 ml of phenol reagent. The solutions were mixed thoroughly and cooled in a cooling bath for 5 min. Next, 0.4 ml of 10-15% NaOCl was added, and the solution was shaken vigorously for 1 min, and again cooled in a cooling bath for 5 min. Finally, the solution was boiled in a water bath (100 °C) for 10 min, and allowed to cool. Optical density was determined by spectrophotometry at a wavelength of 630 nm, with ethanol 2.0 ml as a blank. GABA content was quantified by comparing the optical density reading with the standard GABA content curve and reported in mg/100 g.

2.4.3 Statistical analysis

In this research, the data analysis was carried out using the Statistical Package for Social Sciences (SPSS), analysis of variance (ANOVA) and Duncan's Multiple Range test at the 95% confidence level. The aim of the analysis is to evaluate the significance of the changes in various quality attributes of GBR as a result of steaming and drying treatments.

3. Results and Discussion

3.1 Effects on the GBR moisture content of steaming and drying treatment at varying temperatures

In the experiments, a hot air oven was utilized to dry the GBR samples (i.e. the steamed and non-steamed samples) to the safe storage dryness level of 13-14% w.b. (Chungcharoen *et al*., 2015; Saikusa *et al*., 1994) at the drying temperatures of 20 °C, 40 °C, 80 °C, and 160 °C. The lengths of drying time were varied between 15 min to 24 hrs and between 12 min to 20 hrs for the steamed (SDR) and non-steamed (NSD) GBR samples, respectively. It was observed that the steaming treatment retarded the removal of moisture content from rice kernels for all the drying temperatures under study.

Figure 3 illustrates the relationships between the removal of GBR moisture content at the various drying temperatures and the drying duration. It was found that the moisture removal higher rate is correlated to the increase in the drying temperatures. In Figure 3, it required one day at the low temperature (20 °C) for the rice samples to arrive at the targeted moisture content of 13±1% w.b., while a mere 12 minutes was needed in case of the drying temperature of 160 °C.

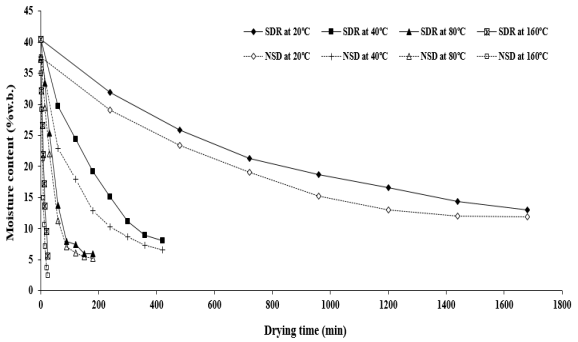

Figure 3. Moisture content relative to drying time of GBR samples at 20 °C, 40 °C, 80 °C and 160 °C.

Dried germinated brown rice currently available in the market is faced with a common problem of post-drying rice cracks, a phenomenon attributable to the water absorbed by brown rice during the germination process and the subsequent swollen germinated rice. This problem could nonetheless be tackled by steaming the germinated rice before drying. Furthermore, in the preliminary experiments in which the steaming time of GBR was varied, the moderate steaming time of about 10 min at 100 °C was found most suitable with better rice appearance and less grain deformation.

3.2 Effects on the GBR physicochemical properties of steaming and drying treatment at varying temperatures

Tables 1 compare the physicochemical properties of the GBR samples under eight different steaming-temperature conditions with those of non-germinated brown rice. In comparison with the non-germinated brown rice, the apparent cooking time, hardness, water absorption, whiteness of rice grain and free fatty acids values of the GBR samples were lower while their total lipids were higher. In addition, the physicochemical properties between the GBR samples under the various experimental conditions are significantly different.

Hardness: In Table 1, the hardness of cooked GBR samples is in the ranges of 22-27 N and 24-30 N for the NSD and SDR rice samples. In general, the hardness values of the GBR samples are lower than the non-germinated brown rice except for the cooked SDR rice sample at the drying temperature of 160 °C, in which its hardness value (30.83±2.15 N) exceeds that of cooked non-germinated brown rice (28.37±3.54 N). In addition, in case of the SDR rice samples, the hardness is positively correlated to the increase in drying temperatures. Statistically, the rise in the hardness is nonetheless insignificantly different ($P>0.05$) at the drying temperatures of 20 °C, 40 °C, and 80 °C, but significantly different ($P<0.05$) at 160 °C. In contrast, the hardness of cooked rice in the case of NSD rice samples is inversely correlated to the rise in drying temperatures. In other words,

Table 1. Physical properties of post-drying GBR under the various steaming-temperature conditions.

Treatment	Physical properties					
	Cooking time (min)	Hardness (N)	Water absorption (g water/ g rice)	Whiteness (%)	Total lipids (%)	Free fatty acid (%)
Brown rice	27.00±0.00^{e}	28.38±3.54^{d}	2.42±0.12^{e}	22.30±0.00^{h}	2.36±0.04^{a}	1.64±0.13^{d}
Non-steamed						
drying at 20 °C	25.00±0.00^{c}	27.62±1.48^{cd}	2.52±0.02^{e}	22.80±0.00^{h}	3.27±0.03^{f}	1.28±0.02^{c}
drying at 40 °C	25.00±0.00^{c}	25.60±1.03^{bc}	2.42±0.01^{e}	21.30±0.00^{g}	3.18±0.04^{de}	1.24±0.02^{c}
drying at 80 °C	26.00±0.00^{d}	24.20±1.38^{ab}	2.19±0.16^{d}	21.00±0.00^{f}	3.02±0.02^{cd}	1.23±0.01^{c}
drying at 160 °C	26.00±0.00^{d}	22.52±1.50^{a}	2.01±0.12^{c}	20.80±0.06^{e}	2.98±0.03^{b}	0.85±0.01^{b}
Steamed 100°C, 10 min						
drying at 20 °C	24.00±0.00^{b}	24.63±1.18^{ab}	1.72±0.04^{a}	16.40±0.00^{b}	3.19±0.02^{ef}	0.89±0.07^{b}
drying at 40 °C	24.00±0.00^{b}	24.83±1.74^{ab}	1.78±0.01^{a}	16.13±0.06^{a}	3.17±0.01^{e}	0.81±0.02^{b}
drying at 80 °C	23.00±0.00^{a}	26.77±1.29^{bcd}	1.84±0.03^{ab}	17.70±0.00^{c}	2.98±0.06^{bc}	0.73±0.01^{a}
drying at 160 °C	23.00±0.00^{a}	30.83±2.15^{e}	1.94+0.01^{bc}	19.53±0.06^{d}	2.96±0.00^{bc}	0.68±0.00^{a}

Data are expressed as the means ± standard deviation of triplicate measurements. Means in the same column that are followed by identical superscript letters are insignificantly different at P<0.05 by Duncan multiple range test.

as the temperatures increased, the hardness declined. According to Jaisut *et al.* (2008), the increased hardness of GBR undergoing the steaming and drying treatment was attributable to the gelatinization of rice starch and the formation of amylose-lipid complex, thus causing starch granules to lose their polygonal shape. In addition, Kim *et al*. (2007) and Chungcharoen *et al*. (2015) documented that in the germination of brown rice, its texture becomes soft to a certain extent owing to the physiological activity of brown rice itself and activities of various enzymes, resulting in a rice type with soft texture and ease of cooking, in relation to normal brown rice. On the contrary, the NSD rice samples are metabolically active and hence exhibit high activities of hydrolases, e.g. α-amylase, which subsequently affects the hardness value. With the passage of time, starch and proteins in NSD rice would decompose while plumules and radicles grow excessively, rendering the germinated NSD brown rice unfit for consumption in addition to a deformation of rice grain shape once cooked.

Water absorption: Interestingly, soaking and incubating brown rice partly contributes to the enhanced palatability of cooked brown rice. In Table 1, the water absorption values of SDR rice samples were significantly (P<0.05) lower than NSD's. It was also found that the water absorption of NSD rice samples significantly decreased from 2.52 to 2.01g water/g rice with the increase in the drying temperatures from 20 to 160 °C. On the other hand, the water absorption of SDR rice samples insignificantly increased from 1.72 to 1.94 g water/g rice with the increase in the drying temperatures from 20 to 160 °C. This could be attributed to subsequent formation of amylose-lipid complexes during steaming and drying, leading to native starch present or formed during cooking that subsequently provides a barrier that reduces starch swelling during cooking and retards water penetration (Jaisut *et al.,* 2008). Thus, the water absorption of cooked SDR germinated brown rice is significantly lower (P<0.05) than that belonging to the NSD group.

Total lipids and free fatty acid: A number of factors can affect rice lipids, e.g. varieties of rice, heat treatment, light, and duration time. In Table 1, the changes in total lipids of GBR could be observed following the steaming and drying treatments. By comparison, total lipids of non-germinated brown rice are the lowest (2.36±0.04%). In the case of NSD rice samples, in relation to the pre-drying GBR, the germinated brown rice dried at 20 °C exhibited a significant increase (P<0.05) in the total lipids (3.27%). Total lipids nevertheless decreased to 3.18%, 3.02% and 2.98% for the drying temperatures of 40 °C, 80 °C, and 160 °C, respectively. A similar trend in total lipids could also be observed for the SDR rice samples. The steaming treatment prior to drying contributed to a lowering in total lipids vis-à-vis the drying treatment alone. For instance, the SDR rice samples with the drying temperature of 20 °C exhibited an insignificantly lower level (P>0.05) of total lipids (3.19%) than that of NSD (3.27%) at the same drying temperature. Furthermore, similar patterns were observed at the drying temperatures of 40 °C, 80 °C, and 160 °C. In comparison with the non-germinated brown rice sample, the free fatty acids content of both SDR and NSD germinated brown rice samples were significantly low, indicating that steaming and drying affected the free fatty acids. The free fatty acid of non-germinated brown rice of 1.64±0.13% was significantly

decreased ($P<0.05$) with germination, steaming and drying treatment. In the NSD case, free fatty acids insignificantly decreased to 1.28%, 1.24% and 1.23% at 20 °C, 40 °C and 80 °C, respectively, and significantly decreased ($P<0.05$) to 0.85% at 160 °C. The results were similar for the SDR case but lower in the values of free fatty acids. Most of the lipids in rice are concentrated on the outer layer; thus, in the germination process, these lipids come into contact with lipases and hydrolyses to form free fatty acids (Piggott *et al*., 1991). Moreover, in the thermal treatments (i.e. moist heat and dry heat), the lipids in rice bran undergo the stabilization process in which active lipases and peroxides are destructed (Juliano, 1994). In addition, the steaming treatment could possibly lower the free fatty acids since the pre-drying non-steamed rice samples exhibited a higher level of free fatty acids than the pre-drying steamed samples.

3.3 Effects on γ-aminobutyric acid (GABA) of GBR (endosperm, whole grain and embryo) of steaming and drying treatment at varying temperatures

Figures 4 and 5 illustrate the effects of drying at different temperatures (i.e. 20, 40, 80, 160 °C) on the GABA content of non-steamed (NSD) and steamed (SDR) germinated brown rice. According to Komatsuzaki *et al*. (2007), a steaming temperature ≤100 °C had no effect on the GABA content. This current research has thus selected a steaming temperature of 100 °C and steaming time of 10 min to reduce microorganisms and give a good appearance of the final products. To determine the condition under which the production of germinated brown rice products could be optimally realized, this research has investigated the accumulation of GABA content during germination in three principal parts of GBR grains (i.e. endosperm, whole grain and embryo). The process started with soaking brown rice for 4 h, after which the moisture content of approximately 35% was achieved, and then incubating for another 20 hrs, after which the GABA content of the germinated brown rice would be in a range of 12.50±0.74 mg/100 g. For the SDR rice group, the post-incubation GBR was steamed to eliminate microorganisms.

The findings revealed that the GABA content is inversely correlated to the drying temperatures. In other words, the content of GABA decreased with increase in the drying temperatures. By comparison, the magnitude of the decline in GABA belonging to the SDR rice group was greater than the NSD group. The GABA contents of post-drying NSD and SDR germinated brown rice were respectively between 7.74±0.34 and 11.51±0.73 mg/100 g and 7.36±0.75 and 9.95±0.40 mg/100 g. In addition, the experimental results showed that the endosperm part contains the lowest content of GABA whose proportion declines with increase in the drying temperature. At the same drying temperatures, the GABA content in the embryos of the SDR rice group was remarkably lower than that of the NSD group. In the case of SDR rice samples, the highest GABA content of 29.24±1.82 mg/100 g was observed in the embryo for the 20 °C drying temperature and it significantly decreased to 27.49±1.25, 24.48±2.12 and 19.97±0.64 mg/100 g for 40, 80 and 160 °C, respectively, a phenomenon attributable to the inactivation of glutamate

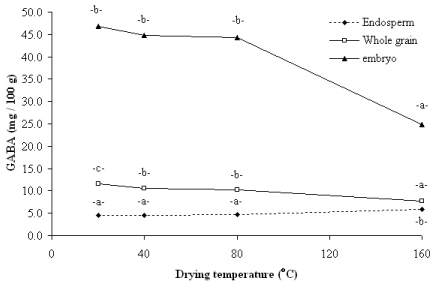

Figure 4. Changes in GABA of non-steamed GBR relative to drying temperatures (means of quintuplicate measurements; means followed by the same letter are insignificantly different at $P<0.05$ by Duncan multiple range test).

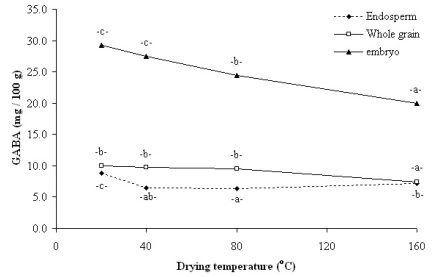

Figure 5. Changes in GABA of steamed GBR for 10 minutes relative to drying temperatures (means of quintuplicate measurements; means followed by the same letter are insignificantly different at $P<0.05$ by Duncan multiple range test).

decarboxylase and proteolytic enzymes. It is thus recommended that fresh or well-preserved embryos be used for GABA production as the high-temperature treatment decomposes the GABA accumulation. These results imply that the GABA content is sensitive to the steaming and subsequent drying at high temperature. Watanabe *et al*. (2004) documented that during the baking process in which the temperature could be as high as 200 °C GABA was almost completely decomposed in both brown rice and germinated brown rice.

4. Conclusions

This research has attempted to determine the effects of drying temperatures (i.e. 20, 40, 80, and 160 °C) on the physicochemical properties of non-steamed drying (NSD) and steamed drying (SDR) germinated brown rice (GBR). The findings revealed that the drying temperatures influenced the physicochemical properties of the final germinated brown rice products. Furthermore, the apparent hardness, water absorption and free fatty acids of both SDR and NSD rice groups were lower than ordinary brown rice, whereas their total lipids were higher. The results also indicated that the GABA content decreased with increase in the drying temperatures and the NSD group's GABA content was higher than the SDR group's, suggesting that high temperature treatment could decompose GABA more rapidly and substantially than low temperature treatment. Despite the heat-induced decomposition, the GABA content in germinated brown rice is still higher than in non-germinated brown rice.

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