Changes in Physicochemical Properties of Parboiled Brown Rice during Heat Treatment

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ABSTRACT

Thai rice varieties with high amylose content (Chainat 1, Supanburi 1) and low amylose content (Koa Dok Mali 105) were used to produce parboiled brown rice. In this study brown rice with the initial moisture content of 13±1% (w.b.) was soaked at two different initial soaking temperatures of 70 and 80^{o} C. The soaking time was 1h, 2h, 3h and 4h, followed by steaming at temperature of 100^{o}C for 10, 15 and 20 min. The samples were then shade dried at 30±1^{o} C and 60±5 %RH to a final moisture content of 13±1% (w.b.). Physicochemical properties were determined and sensory analysis was performed for selected processing conditions. Head rice yield, yellowness (b-value), whiteness, hardness, water absorption, vitamin E and vitamin B2 were measured and compared with those of commercial parboiled paddy. Results revealed that the head rice yield, color (b-value), cooking time and hardness of parboiled brown rice were decreased whereas whiteness and water absorption were increased compared with commercial parboiled paddy. Qualitatively, parboiled brown rice showed intermediate values between milled rice and commercial parboiled paddy. Sensory analysis revealed high acceptance of cooked parboiled brown rice from the panelists. However, presence of vitamin B2 decreased and vitamin E disappeared after parboiling process on brown rice. Head rice yield was lower for parboiled brown rice when compared to that of parboiled paddy but greater than the head rice yield of non-parboiled rice.

Keywords: Parboiling process, parboiled brown rice, brown rice, heat treatment, Thailand

1. INTRODUCTION

Rice (*Oryza sativa* L.) is considered as a main staple food and is a major source of nutrients in many parts of the world. Today, consumers prefer to eat unpolished rice because of the nutrient value in the bran. Therefore, demands for brown rice and parboiled rice are increasing because of their reputation for nutritional excellence and health claims associated with eating this type of rice. However, brown rice has some disadvantages such as slower absorption of liquid into the kernel because the bran in brown rice contains fiber, which leads to prolonged cooking time. Furthermore, the oil content in the bran shortens its shelf life, as the bran becomes rancid. Therefore, parboiling is one alternative to reduce these problems. Normally, parboiling consists of three different operations, namely soaking in water, steaming to complete gelatinization of the starch and drying. These processes require more energy and longer time. A method to avoid loss of free water to evaporation during soaking and to save on time and energy use, starch gelatinization can be achieved by exposing rough rice with sufficient amount of water added to microwave energy (Velupillai et al., 1989). The primary objective of parboiling is to improve the rice quality and obtain higher milling yield. The parboiled produce exhibit several advantages over unparboiled product such as the strengthening of kernel integrity, increased milling recovery, prevention of the loss of nutrients during milling and improved shelf life as well as prevention of the proliferation of fungus and insects (Rao and Juliano, 1970a, Bhattacharya, 1985). However, parboiling produces some undesirable affects, for example, parboiling of rough rice at high temperature and the long steaming time generally produces a dark color and harder product (Bhattacharya, 1985; Kimura *et al*., 1993). These products fetch lower price in the market. In addition, parboiled rice has a peculiar smell and taste, requires longer cooking time and costs morehigher in price than white rice, which leads to fewer acceptances among people, particularly in Thailand.

Thailand is a leading rice exporter, especially of parboiled rice. Parboiled rice is actively produced in Thailand for export mainly to South Africa, Nigeria and various countries in Asia, Europe, the Mediterranean and the Middle East. Popular rice varieties, used to produce parboiled rice, are Chainat 1 and Supanburi 1. The latter has better yield and insect-resistant characteristics and offer product quality similar to Chainat 1. Parboiling improve rice quality and thus fetch higher product price.

Aromatic rice (Koa Dok Mali 105) variety having low amylose content is not used in parboiling because of its softness after cooking and higher price. However, some consumers prefer to eat low amylose content rice but do not like the stickiness of the cooked rice. Parboiling process can improve the hardness of the low amylose rice. Because high amylose content rice requires longer process time for parboiling, and thus consumes more energy (Saifullah et al., 2004), using low amylose content rice may be lead to a reduction in energy costs, decreased grain yellowness and cooking time, a gain in texture, smell, and preference to consumers.

Generally, parboiled rice produced from rough rice leads to increased yellowness, undesirable smell during soaking and retarded heat transfer to the kernel because siliceous husk does not wet easily and resists water movement into the kernel (Bhattacharya and Subba Rao, 1966a,b). Consequently, parboiled brown rice is an attractive alternative. As reported by Bhattacharya (2004), a shift to brown rice parboiling was noted during the last 20 years. The use of brown rice has several advantages, e.g. faster hydration, low weight and volume leading to parboiling faster and cheaper processing. The effectiveness of parboiled paddy in improving the quality of milled rice is well known (Bhattacharya and Subba Rao, 1966a,b; Priestley, 1976; Juliano *et al*., 1981; Marshall *et al*., 1993), but very little published literature is available on the physical property change of parboiled method from paddy to brown rice especially in Thai rice varieties.

The main objective of this study was to determine the optimum conditions and changes in physicochemical properties of two high amylose content rice varieties; Chainat 1 and Supanburi 1 and a low amylose variety, KDML105 at different conditions of parboiled brown rice treatment. The performance indicators of parboiled brown rice were head rice yield, hardness, water absorption, whiteness, color (b-value) and sensory evaluation. They were compared with those of the commercial parboiled paddy.

2. MATERIALS AND METHODS

2.1 Sample Preparation

2.1.1 Preparation of Paddy

Three local varieties of long grain rough rice consisting of Chainat 1, Supanburi 1 and KDML 105 from Sisaket province, Thailand were used. The average initial moisture content of rice grain was 13±1% (w.b.). Before conducting the experiment, rough rice packed in a 5 kg polyethylene bag were stored in a refrigerator at 10^{o} C.

2.1.2 Preparation of Brown Rice

After removing the stored paddy from the refrigerator, samples were brought to room temperature by holding for 1 day. Samples were shelled by a rubber roll sheller and graded for separating the broken kernels.

2.2 Parboiling Process

2.2.1 Soaking Condition

For the absorption study, the procedure described by Fan *et al*. (1999) was followed. Initial soaking temperatures of 70^{o} C and 80^{o} C were used to produce parboiled brown rice. Samples weighing 500 g of brown rice were soaked in filter cloth immersed in hot water for 1h, 2h, 3h and 4 h and then drained. The soaked brown rice was tempered at ambient temperature for 30 min.

2.2.2 Steaming Condition

The second step of the parboiling process is steaming to improve rice moisture to 30–35% (w.b.) (Kimura, *et al*., 1976; Bhattacharya, 1985) and heat treatment also irreversibly gelatinizes the starch. Steaming was done using an autoclave at 100^{o} C (14.698 lb_f/in^2) for 10, 15 and 20 min.

2.2.3 Drying condition

The steamed rice was then dried on trays at room temperature (30±1^{o} C, 60±5 %RH) resulting in the final moisture content of 13±1% (w.b.). After drying, samples were stored in airtight polyethylene bags for moisture equilibration and hardness stabilization (Kimura, 1991). Physicochemical analyses were performed after two weeks.

The effects of initial soaking temperature, soaking time and steaming condition on various quality parameters were investigated. Two initial soaking temperatures (70, 80^{o} C), four soaking times (1h, 2h, 3h and 4 h) and three steaming times (10, 15 and 20 min) were evaluated. Hence, twenty four of treatment combinations were tested, as shown in Table 1.

Table 1. Treatment combinations for parboiling of brown rice

Treatment	Experimental conditions			
	Soaking process		Steaming process (14.698 lb_f/in^2)	
	Initial temperature (^oC)	Time (h)	Temperature (^oC)	Time (min)
T_1	70	1	100	10
T_2	70	1	100	15
T_3	70	1	100	20
T_4	70	2	100	10
T_5	70	2	100	15
T_6	70	2	100	20
T_7	70	3	100	10
T_8	70	3	100	15
T_9	70	3	100	20
T_{10}	70	4	100	10
T_{11}	70	4	100	15
T_{12}	70	4	100	20
T_{13}	80	1	100	10
T_{14}	80	1	100	15
T_{15}	80	1	100	20
T_{16}	80	2	100	10
T_{17}	80	2	100	15
T_{18}	80	2	100	20
T_{19}	80	3	100	10
T_{20}	80	3	100	15
T_{21}	80	3	100	20
T_{22}	80	4	100	10
T_{23}	80	4	100	15
T_{24}	80	4	100	20

2.3 Physicochemical Properties

2.3.1 Moisture Content

The moisture content of brown rice was determined by the standard oven method. Three 30g samples were dried in hot air oven at 130^{o}C for 16 h (Mathews, 1962). Moisture content was expressed on a wet basis (w.b.).

2.3.2 Head Rice Yield

The head rice yield consisted of rice three-fourth in size to whole kernel. For each milling test, paddy samples (250 g each) were cleaned before passing through a Satake rubber roll huller (Model THU 35A, Japan). Broken rice was separated from head rice before parboiling using a Satake grader (Model TRG05B, Japan) process. Head rice yield was determined three times. The brown rice samples were then soaked, steamed and dried. After that the dried samples were polished using a Satake rice polisher (Model TM05, Japan). .

2.3.3 Cooking time

Two lots of ten grams of rice sample was mixed with 70 ml distilled water in 100ml beaker and cooked at 97-99^{o}C in cooker (Toshiba, Model RC-18R) and the other in water bath (Clay, Model WB 30CT). Cooking time was recorded for both cooker and water bath. After

10 min of cooking, ten grains were randomly removed and pressed between two glass plates. The number of translucent kernels were counted and recorded. Sampling was done every 2 min interval and rice grains were analyzed until the end of the cooking cycle. The time at which 90% of the kernels were translucent was considered to be the cooking time (Juliano, 1982).

2.3.4 Hardness

Hardness of cooked rice was measured following the calculated water method (Juliano, 1985; Banjong, 1986). Samples weighing 25 g with predetermined amount of distilled water were placed in 100 ml beakers. These beakers were placed in cooker with 400 ml water in the outer pot. The hardness of cooked rice samples was measured by back extrusion test (Texture Analyzer LLOYD model LRX plus, United Kingdom). This method was modified from a small sample back extrusion test (Reyes and Jindal, 1990). The average bio-yield point value was expressed as the hardness of parboiled brown rice in Newton (N).

2.3.5 Water Absorption

The method proposed by Sabularse *et al*. (1991) was used with modifications to determine water absorption. Two gram of rice was mixed with 20 ml distilled water in a test tube covered with a piece of cotton plug. The test tube was then placed in a thermostatically controlled water bath preheated to 97-99^{o} C for cooking the rice. This was then followed by cooling in water, draining of excess water, and the test tube placed upside down for 1 h and then weighed. Water absorption was calculated as increase in weight, and expressed as gram of water per gram of rice.

2.3.6 Whiteness and Color Value

Whiteness of the parboiled rice sample was measured using a Kett digital whiteness meter (Model C-300, Japan). Before measurement, the meter was calibrated against standard white to a percent whiteness of 88.1.

Color of milled rice was measured as a function of the tristimulus factor values, using a Color Difference Meter (Model JC801, Japan). The color was toward yellowness (b-value) of the sample and compared against the quality of parboiled paddy.

Other indicators such as amylose content, vitamin B2 and vitamin E were also determined following Juliano (1982), AOAC (1995) method 970.65 and AOAC (1993) method 39.1, respectively.

2.3 Sensory Evaluation

Flavor and texture characteristics of cooked parboiled rice are the important sensory parameters for determining suitability of parboiled brown rice. The sensory evaluation was performed by 10 semi-trained panelists. They were Thai students of 18-22 years age. A scale of 1-5 was used, representing five categories, vis-a-vis dislike, like slightly, like moderately, like very much and like extremely. Sensory attributes of cooked parboiled rice that were subjected to evaluation were aroma, color, grain separation, grain shape, texture, stickiness, taste and overall acceptability.

2.4 Statistical Analysis

The parboiled brown rice treatment and all analyses were performed in triplicate. One – way analysis of variance (ANOVA) was used (significance level $P < 0.05$) to analyze data by using the SPSS (Statistical Analysis System Software) version-11.

3. RESULTS AND DISCUSSION

The apparent amylose content of the three rice varieties- KDML 105, Supanburi 1 and Chainat 1 was 19.30%, 35.10% and 37.20% respectively. Parboiled brown rice with different soaking-steaming temperature and time combinations was prepared and dried in the shade, and based on the amylose content was separated into two groups as low amylose content (KDML 105) and high amylose content (Supanburi 1 and Chainat 1) rice.

3.1 Effect of Heating Condition on Physical Properties of Parboiled Brown Rice

3.1.1 Moisture Content after Steaming

Table 2. Moisture content after steaming at various soaking conditions with three varieties (Chainat 1, Supanburi 1 and KDML 105)

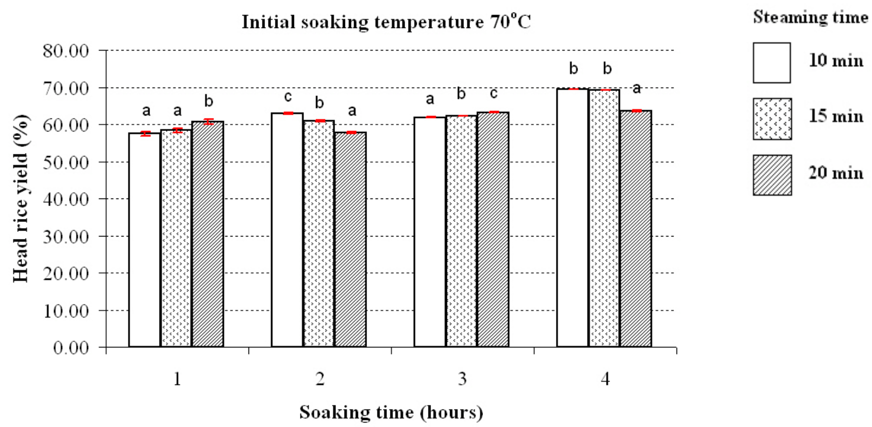
Soaking conditions		Moisture content (% w.b.)								
Initial		Chainat 1			Supanpuri 1			KDML 105		
temperature	Time	Steaming time (min)			Steaming time (min)			Steaming time (min)		
(^{o}C)	(hours)	10	15	20	10	15	20	10	15	20
70	1	33.96	34.91	35.78	34.02	34.62	35.67	37.70	38.33	38.72
	2	34.16	34.58	35.71	36.65	36.79	37.76	39.43	38.97	39.24
	3	36.52	37.21	37.64	36.96	37.23	38.30	39.85	39.54	40.08
	4	37.18	38.08	38.92	37.12	38.84	40.50	40.42	40.17	41.88
80	1	36.52	36.58	36.47	35.92	36.12	37.18	42.56	43.56	43.85
	2	37.28	37.80	37.89	37.59	38.00	38.26	46.25	47.49	48.99
	3	38.59	38.78	39.51	39.22	39.45	40.47	48.41	49.98	50.88
	4	39.55	40.06	40.34	40.64	41.27	41.73	51.16	51.47	52.24

Soaking is normally done to achieve quick and uniform water absorption (Wimberly, 1983). The average moisture content at different steaming conditions for three rice varieties is shown in Table 2. Gariboldi (1985) reported that the required moisture content for properly hydrated soaked paddy for parboiling was around 30%, which was also observed in this study. For high amylose content group the results indicated that moisture content increased rapidly from an initial value of 13±1% to 33 to 38% after 1 h of soaking, and then flattened gradually. Similar observations were made by Lin, 1993; Marcelo *et al.*, 2004. For both high amylose varieties, after steaming for 10-20 min, moisture content was about 33 to 40% at the 70^{o} C initial temperature of soaking water and 36 to 42% at 80^{o} C. Moisture content, after steaming of low amylose content group, was also analyzed. The results indicated that low amylose variety (KDML 105) absorbed water easily and had the highest value of moisture content at T_{24} of 52.24% and the lowest value at T_1 of 37.70%. From appearance of the rice kernels, it was observed that kernels de-shaping occurred in KDML 105 samples with high moisture content (> 40%). Kadus *et al.* (2002) reported that hot soaking for longer durations allows disruption of hydrogen bonds and weakens the micellar structure of starch granules. Thus, this affected the head rice yield and hardness as shown in the Figures 2 (c) and Tables 4 of treatment 24. However, de-shaping of the parboiled brown rice only occurred in the low amylose content rice variety (KDML 105) but not in the high amylose content rice varieties.

3.1.2 Head Rice Yield

The relationship between head rice yield and soaking time of brown rice at different steaming time is presented in Figures 1-2. This study only looked at the effects of two initial soaking temperatures of 70^o C and 80^o C for 1-4 h, and various steaming time on head rice yield. It was observed that the head rice yield value was varied from 54% to 71% for all three rice varieties. The head rice yield of Chainat 1 showed significant increase ($P<0.05$) from 66% to 71% with increase in soaking time at initial temperature of 80^o C and longer steaming time (10-20 min), whereas at low temperature soaking (70^o C) the results showed fluctuation in head rice yield values. The head rice yield value of Suphanburi 1 was varied from 64% to 71% when soaking at initial temperature of 70^o C and increased with soaking and steaming time, whereas soaking at high temperature (80^oC) for 4 h showed slightly decrease in head rice yield. However, it was found that the soaking and steaming of each rice variety at the suitable conditions was increased the head yield of parboiled rice which further caused gelatinization process that brings stronger structure and the denaturation of protein by diffusing into inter-granular space of starch which further increases the binding effect, and is better for milling process (Gariboldi, 1974). In addition, the moisture content was removed slowly from parboiled brown rice in the shade, although it takes longer but gives an excellent milling quality.

For KDM 105, after 1 h of soaking at initial temperature of 70^o C head rice yield of parboiled brown rice showed significant increase ($p<0.05$) for 10-15 min steaming whereas steaming for 20 min showed slightly significant decrease. However for the same of soaking time (1 h) with higher initial temperature of 80^o C head rice yield showed significant increase ($P<0.05$) for 10-20 min steaming. In addition, head rice yield values were found decreased with longer time for soaking and steaming such as at treatment 24, soaking at initial temperature 80^o C for 4 h and steaming for 20 min, showed the lowest head rice yield value (54%). It might be during soaking brown rice (low amylose content) at higher temperature was found that severe deformation of the grain that loses the exuded party the endosperm while absorbing excessive moisture which led to reduced milled yield (Islam *et al*., 2004; Bello *et al*., 2006). Therefore, longer duration for soaking and steaming are not suitable for parboiled brown rice especially with low amylose content (KDML 105).



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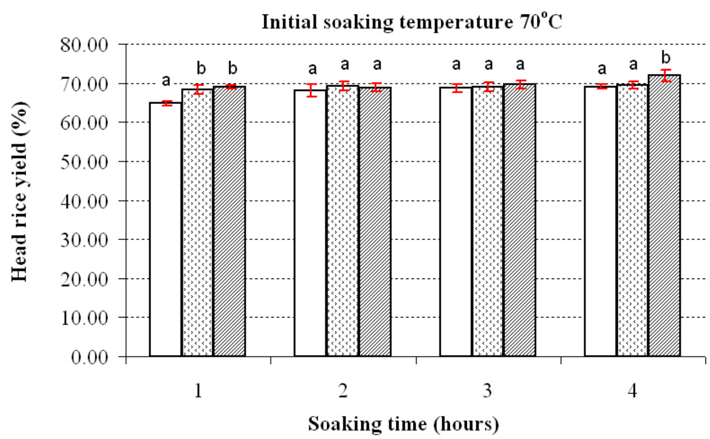

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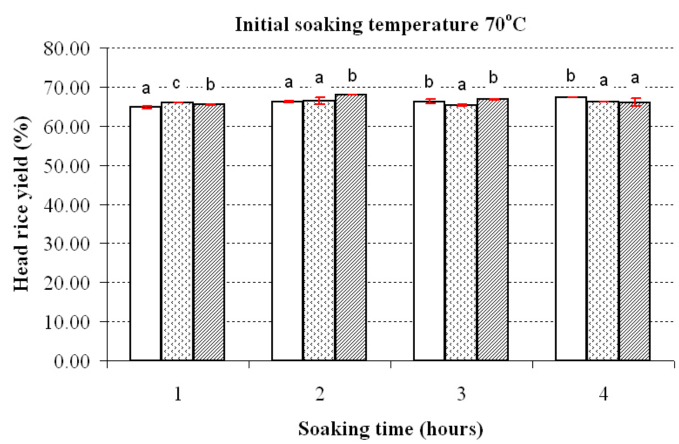
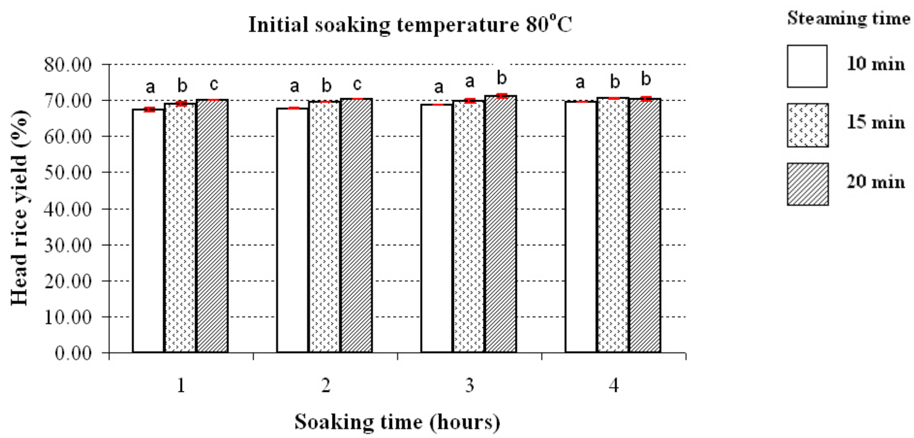
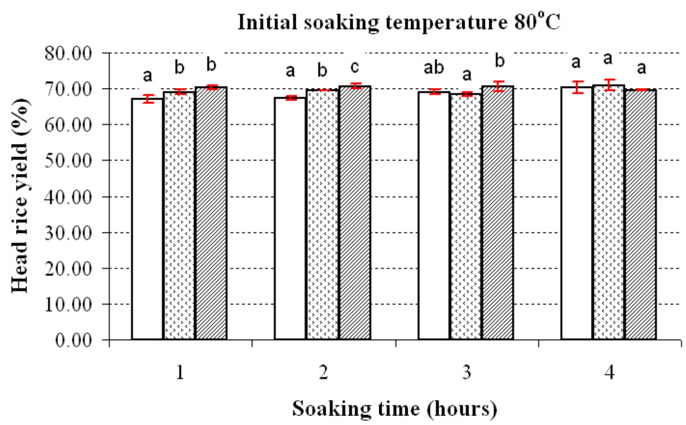


(c)

Figure 1. Effect of head rice yield of three rice varieties of parboiled brown rice with different soaking time at initial soaking temperature 70°C
(a) Chainat 1 (b) Supanburi 1 (c) KDML 105



(a)



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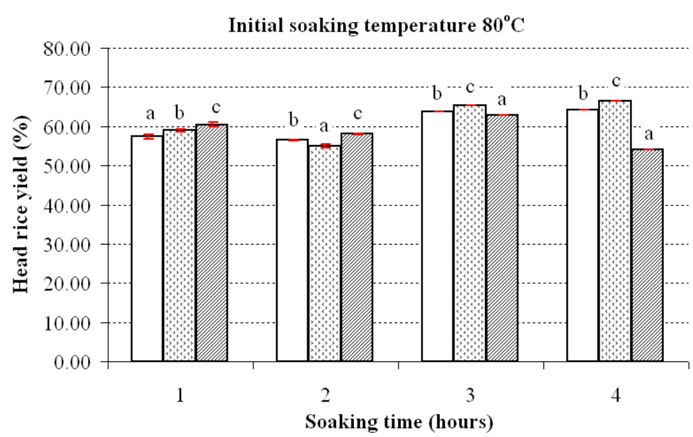

(c)

Figure 2. Effect of head rice yield of three rice varieties of parboiled brown rice with different soaking time at initial soaking temperature 80°C
(a) Chainat 1 (b) Supanburi 1 (c) KDML 105

Table 3. Effect of parboiling brown rice on cooked rice quality of high amylose content rice (Chainat 1 and Supanburi 1)

Ex.	*Chainat 1				*Supanburi 1			
	Hardness (N)	Color (b-value)	Whiteness (%)	Water ab. (g rice / g water)	Hardness (N)	Color (b-value)	Whiteness (%)	Water ab. (g rice / g water)
T_1	39.61±0.58	9.53±0.040	43.63±0.35	2.85±0.06	33.49±1.04	9.72±0.09	40.60±1.18	3.06±0.10
T_2	43.76±0.30	9.73±0.01	43.43±0.29	2.71±0.06	36.50±1.41	9.88±0.29	39.77±0.47	2.93±0.07
T_3	44.84±1.12	9.80±0.17	42.07±0.23	2.53±0.05	39.30±0.47	10.28±0.21	39.10±0.56	2.69±0.04
T_4	40.16±1.82	9.63±0.25	41.73±0.21	2.62±0.08	38.19±1.13	9.60±0.13	39.47±0.57	2.87±0.05
T_5	42.76±0.75	9.73±0.42	41.53±0.12	2.54±0.04	38.59±1.19	9.73±0.13	38.43±0.46	2.61±0.10
T_6	45.83±0.61	10.30±0.44	41.60±0.40	2.51±0.08	40.23±0.56	10.27±0.21	36.87±0.11	2.59±0.11
T_7	43.25±0.03	9.80±0.02	40.21±0.07	2.50±0.02	39.94±2.23	9.65±0.07	38.55±0.58	2.76±0.08
T_8	44.58±0.01	10.14±0.44	40.63±0.06	2.41±0.01	41.71±1.13	9.93±0.07	37.11±0.01	2.45±0.06
T_9	45.98±0.04	10.89±0.25	40.25±0.04	2.39±0.01	43.39±1.09	10.33±0.32	36.43±0.60	2.32±0.02
T_{10}	46.62±1.42	10.10±0.10	39.93±0.57	2.48±0.07	40.90±0.70	10.08±0.04	37.97±0.35	2.73±0.08
T_{11}	47.58±1.46	10.50±0.36	37.57±0.51	2.29±0.01	42.91±2.39	10.20±0.37	37.16±0.47	2.45±0.04
T_{12}	47.96±0.67	11.23±0.31	39.27±0.31	2.26±0.23	43.87±0.70	10.82±0.23	36.30±0.44	2.24±0.03
T_{13}	42.15±0.02	9.23±0.03	46.57±0.56	2.61±0.02	40.11±0.50	9.42±0.20	40.88±0.57	2.77±0.10
T_{14}	43.25±0.05	9.49±0.03	45.15±0.97	2.60±0.01	41.58±1.02	9.60±0.21	39.99±0.51	2.69±0.01
T_{15}	44.69±0.02	9.52±0.01	43.62±4.13	2.59±0.01	42.72±0.59	10.24±0.07	39.29±0.79	2.57±0.05
T_{16}	43.75±1.43	9.40±0.10	45.87±1.00	2.56±0.04	42.42±0.59	9.77±0.15	40.13±0.25	2.72±0.06
T_{17}	44.83±1.59	9.33±0.15	44.37±0.50	2.42±0.07	42.65±0.60	10.10±0.10	39.73±0.25	2.61±0.03
T_{18}	46.19±0.86	9.67±0.21	42.63±0.31	2.40±0.13	43.17±0.70	10.47±0.25	38.07±0.97	2.38±0.05
T_{19}	44.56±0.03	9.81±0.09	43.19±0.55	2.41±0.02	43.58±0.59	10.06±0.06	38.85±0.58	2.60±0.03
T_{20}	45.25±0.02	10.19±0.11	42.32±1.02	2.36±0.03	44.52±0.57	10.59±0.06	38.04±0.24	2.52±0.05
T_{21}	46.96±0.13	10.63±0.12	42.11±0.03	2.24±0.02	45.45±0.60	10.91±0.11	36.78±0.57	2.31±0.01
T_{22}	45.26±0.75	10.53±0.55	41.53±0.61	2.39±0.08	45.39±0.60	9.87±0.21	38.84±0.60	2.55±0.03
T_{23}	46.05±0.71	10.83±0.25	42.13±0.31	2.31±0.07	45.43±0.56	10.33±0.21	38.13±0.40	2.38±0.10
T_{24}	48.69±0.44	11.33±0.47	41.90±0.70	2.20±0.05	46.76±0.62	10.78±0.20	36.40±1.02	2.36±0.02

* Values are expressed as mean ± S.D. (n = 3)

3.1.3 Hardness

Hardness is the most important physical properties of parboiled rice among all the physical properties, as it reduces breakage during milling which further makes significant influences in increasing the market value and consumer acceptability. It is generally understood that cooked parboiled rice is harder and less sticky than raw cooked rice (Islam *et al.,* 2001). Hardness value is greatly affected by parboiling condition such as starch gelatinization and amylose content. For the high amylose content varieties (Chainat 1, Supanburi 1; Table 3), hardness value increased with soaking time from 1 to 4 h at 70^o C and steaming 10-20 min from 39.61 to 48.69 N and 33.49 to 46.76 N for Chainat 1 and Supanburi 1, respectively. In addition, both varieties indicated high hardness values with increasing initial soaking temperature to 80^o C.

For low amylose rice (KDML 105; Table 4), the hardness decreased with increasing soaking time. Similar to high amylose rice, hardness increase with increasing steaming time. At 70^o C soaking initial temperature for 2 h and then steaming time for 15 min, hardness was 18.40 N.

Upon increasing steaming time to 20 min, the hardness value increased to 19.39 N. However increasing soaking initial temperature to 80^{o} C, 4 h soaking time and steaming for 20 min, hardness value was found to be the lowest (14.13 N). It was probably due to deformation of the grain and exposed endosperm after grain splitting sharply decreased hardness value (Islam *et al.*, 2004). This behavior was noticed only in KDML 105 – having low amylose content and low gelatinization temperature. On the contrast, it did not appear in the high amylose varieties of Chainat 1 and Supanburi 1.

Table 4. Effect of parboiling brown rice on cooked rice quality of low amylose content rice (KDML 105)

	KDML 105			
Ex.	Hardness (N)	Color (b-value)	Whiteness (%)	Water absorption (g rice / g water)
T_1	16.73±0.21	10.20±0.10	38.00±0.36	2.07±0.08
T_2	17.38±0.68	10.33±0.21	37.13±0.60	2.00±0.06
T_3	18.43±1.03	10.43±0.12	36.70±0.00	1.96±0.06
T_4	17.95±0.65	10.37±0.15	37.63±0.15	2.05±0.05
T_5	18.40±0.40	10.38±0.08	36.57±0.93	1.99±0.06
T_6	19.39±0.64	10.53±0.29	35.23±0.55	1.93±0.03
T_7	17.96±0.91	10.44±0.21	37.21±0.20	2.03±0.02
T_8	17.96±0.09	10.60±0.08	35.87±0.64	1.95±0.02
T_9	18.12±0.47	10.82±0.06	34.21±0.03	1.92±0.02
T_{10}	17.68±1.23	10.63±0.06	35.97±0.50	2.02±0.01
T_{11}	17.47±0.50	10.73±0.21	34.66±0.54	1.97±0.07
T_{12}	17.15±0.74	10.83±0.15	33.23±0.31	1.91±0.01
T_{13}	18.21±0.16	10.18±0.12	38.97±0.21	2.31±0.09
T_{14}	19.98±0.11	10.32±0.06	36.52±0.17	2.17±0.05
T_{15}	19.92±0.60	10.58±0.06	35.55±0.48	2.11±0.04
T_{16}	20.02±0.77	10.33±0.06	38.03±0.59	2.22±0.04
T_{17}	20.35±0.61	10.43±0.06	35.43±0.12	2.12±0.03
T_{18}	20.20±1.18	10.47±0.03	34.97±0.47	2.08±0.06
T_{19}	19.19±0.58	10.36±0.02	36.29±1.05	2.23±0.02
T_{20}	18.65±0.02	10.67±0.06	34.90±0.55	2.14±0.02
T_{21}	19.11±0.04	10.63±0.06	33.22±0.05	2.05±0.04
T_{22}	18.17±0.95	10.57±0.06	36.47±0.21	2.10±0.04
T_{23}	17.51±1.01	10.77±0.06	34.27±0.42	2.02±0.01
T_{24}	14.13±0.86	10.90±0.26	32.40±0.61	1.91±0.01

* Values are expressed as mean ± S.D. of three determinations.(n = 3)

3.1.4 Water Absorption

Water absorption properties of parboiled brown rice at different conditions are shown in Tables 3-4. Water absorption was determined based on controlled cooking time by which Chainat 1, Supanburi 1 and KDML 105 had an optimum cooking time at 23, 28 and 14 min, respectively. Water absorption during cooking of Chainat 1 and Supanburi 1 were found higher than KDML 105 which was reduced upon increasing soaking and steaming time. For Chainat 1, water absorption reduced from 2.85 to 2.20 g/g during 1-4 h of soaking and 10-20 min of steaming. Similarly for Supanburi 1, water absorption decreased from 3.06 to 2.24 g/g whereas for KDML 105 it reduced from 2.07 to 1.91 g/g. Decrease in water absorption of parboiled brown rice might be due to starch granules modified by heating and parboiling process. Therefore, stronger structure was obtained and difficult for water penetration into kernel.

3.1.5 Color (b-value)

Parboiling affects the color of milled rice. Color of parboiled brown rice changes from white to yellow upon altering different processing parameters including the soaking water temperature, soaking, and heating duration (Bhattacharya and Subba Rao, 1966a), as shown in Tables 3-4. The b-values of parboiled brown rice ranged from 9.23-11.33. After soaking at 1-4 h at the initial temperatures of 70^{o} C and 80^{o} C, followed by steaming time at 10-20 min, it was found that b-value increased for all three rice varieties. Moreover, b-value was not only affected by steaming time, but also affected by soaking temperature. At a given soaking time, higher soaking temperature gave higher b-value. Thus, increasing soaking temperature and time resulted in higher yellowness. Normally, discoloration of parboiled rice is directly related with the market value because in most countries consumers do not accept dark colored parboiled rice. Changing in b-value of parboiled brown rice was mainly caused by Maillard type non-enzymatic browning (Pillaiyar and Mohandas, 1981; Kimura *et al*., 1993; Bhattacharya, 1996ab). Besides, the contribution of pigments to coloration of parboiled rice is supported by the fact that some nutrients from the bran compounds (lipids) leached out during parboiling (Framalingham, 1996). Therefore, the poor qualities of parboiled rice occurred due to high heat treatments during three main steps of parboiling process (soaking, steaming and drying) can be improved by parboiling at low heat treatments (Islam *et al.*, 2002).

3.1.6 Whiteness

Whiteness value is another factor that influences the price of parboiled rice. Several researchers have reported that the temperature and period of soaking and steaming significantly influence whiteness of parboiled rice (Kimura *et al.*, 1993, Bhattacharya, 1996). Tables 3-4 show the effects of parboiling treatments on the whiteness value under different soaking and steaming conditions. Chainat 1, Supanburi 1 and KDML 105 showed similar responses on whiteness value. Whiteness value decreased with increasing soaking time, soaking temperature and steaming time. Parboiling reduced the whiteness value of Chainat 1 from 43.63% to 37.57%, Supanburi 1 from 40.88% to 36.30% and KDML 105 from 38.00% to 32.40%. These results revealed that lower steaming temperature and time were favorable to produce a better quality of parboiled brown rice (Islam *et al.*, 2002).

Parboiling process using brown rice as raw material revealed different qualities based on soaking and steaming condition. Chainat 1 and Supanburi 1 showed similar trends, probably due to their similar high amylose content. However, on physical appearance of the kernel, Chainat 1 was slightly bigger in size than Supanburi 1, so the optimum condition on parboiled brown rice took longer and corresponding rheological properties were also higher than Supanburi 1. Therefore, Chainat 1 was soaked in hot water of initial temperature 70-80 ^{o} C for 2-4 h and steamed at 100^{o} C for 20 min resulted good appearance. Moreover, at these conditions no any grain deformation was appeared in final product of Chainat 1 , whereas Supanburi 1 had some splits and deformation in grain shape if steamed at 20 min. For this reason, steaming at 20 min was not found suitable for Supanburi 1; consequently, 15 min steaming was more optimal for controlling quality. For KDML 105, soaking and steaming condition also affected the product quality of parboiled brown rice. Soaking at initial temperature 70-80^{o} C for 2 h and steaming 10 min was found to be optimal as no deformation of the kernels occurred. As mentioned in the methodology, the optimum conditions for parboiled brown rice products for the no any grain deformation was appeared in final product of Chainat 1 three rice varieties were selected to perform sensory evaluation.

3.2 Sensory Evaluation

The results on no any grain deformation was appeared in final product of Chainat 1 physical properties of parboiled brown rice are shown in Figures 1-2 and in Tables 3-4. The optimum parboiling condition for each rice variety was different. Thus, the four best treatments for parboiled brown rice for Chainat 1, Supanburi 1 and KDML 105 were selected base on all physical properties and good product appearance for sensory evaluation and compared with commercial parboiled rice. The results of the sensory evaluations are shown in Table 5.

For Chainat 1, there were no significant differences (P>0.05) in grain shape of cooked brown rice when compared to commercial parboiled rice and milled rice. The panelists did not report differences (P>0.05) in aroma, color, texture, stickiness and taste between milled rice and parboiled brown rice but these properties were significantly different (P<0.05) for commercial parboiled rice. For texture and taste, commercial parboiled rice received low scores. The panelists did not like cooked parboiled rice using paddy as raw material and hence it scored the lowest in overall acceptability. The panelists expressed more satisfaction for aroma, color, grain shape, texture, grain separation and taste for parboiled brown rice than for milled rice and commercial parboiled rice as evidenced by the significantly higher overall acceptability score given to parboiled brown rice ($T_{24,}$ P<0.05) .

For Supanburi 1, the panelists could not detect any significant changes on grain shape between parboiled rice and milled rice (P>0.05) for all samples. Other sensory qualities of aroma, color, grain separation, texture, stickiness and taste showed significant difference (P<0.05) between parboiled brown rice and commercial parboiled rice. But no significant difference (P>0.05) was found between parboiled brown rice and milled rice. Commercial parboiled rice scored the lowest for texture and taste. In overall acceptability, the panelists gave the highest score of 4.30 for T_{11} and lowest score for commercial parboiled rice at 2.20, resulting in significant difference (P<0.05). Apparently, changes in qualities of cooked rice resulting from the parboiling process, in particular parboiled paddy drove consumers to reject the product.

The KDML 105 has not showed significant different (P>0.05) in stickiness and taste of cooked parboiled brown rice when compared to milled rice but had significant different (P<0.05) with commercial parboiled rice especially as taste of cooked commercial parboiled rice having lowest score (1.30). It clearly indicated that panelists do not prefer cooked commercial parboiled rice. The lowest and highest scores were observed for cooked milled rice and cooked commercial parboiled rice as 4.00 and 2.20 respectively. These values showed significant different (P<0.05) from cooked parboiled brown rice. Furthermore, cooked milled rice presented highest score not only for overall acceptability but also for aroma, color and grain separation. However, the comparison results of commercial parboiled rice and parboiled brown rice were indicated that the aroma, color, texture, stickiness and taste were significantly different ($P<0.05$) whereas these is no significant difference in grain separation and grain shape were not. Although, panelists accepted cooked milled rice than cooked parboiled brown rice but parboiled brown rice presented higher score for overall acceptability at treatment 4 as 3.40 than other treatment of parboiled brown rice.

According to the sensory evaluation, the preference of panelists was for all parboiled brown rice. Moreover, lower sensory score presented in commercial parboiled rice was attributed to changes in taste, texture and aroma mainly contributing to decline in overall acceptability of cooked parboiled rice samples.

Table 5. Effect of parboiled brown rice and commercial parboiled rice on sensory analysis of three rice varieties (Chainat 1, Supanburi 1 and KDML 105)

Rice variety	Condition	*Sensory Quality (Cooked rice)							
		Aroma	Color	Grain separation	Grain shape	Texture	Stickiness	Taste	Overall acceptability
Chainat 1	Commercial (CPR)	2.10±0.88a	2.10±0.74a	3.40±0.52a	3.50±0.85a	1.30±0.48a	2.00±0.67a	1.30±0.48a	2.20±0.63a
	Milled rice	3.30±0.48b	3.50±0.53b	3.80±0.42ab	3.70±0.67a	3.70±0.48b	3.50±0.53b	3.20±0.42b	3.60±0.52b
	T_{6}	3.50±0.53b	3.50±0.53b	3.80±0.42ab	3.40±0.52a	3.60±0.52b	3.50±0.53b	3.30±0.48b	3.80±0.42bc
	T_{12}	3.60±0.52b	3.50±0.71b	3.80±0a.42b	3.30±0.48a	3.70±0.48b	3.50±0.53b	3.30±0.48b	3.90±0.32bc
	T_{18}	3.70±0.48b	3.70±0.67b	3.90±0.32b	3.70±0.67a	3.80±0.42b	3.50±0.53b	3.30±0.48b	4.10±0.57bc
	T_{24}	**3.80±0.63b**	**3.90±0.74b**	**4.00±0.47b**	**3.70±0.67a**	**3.80±0.42b**	**3.50±0.53b**	**3.30±0.48b**	**4.30±0.67c**
Supanburi 1	Commercial (CPR)	2.10±0.88a	2.10±0.74a	3.40±0.52a	3.50±0.85a	1.30±0.48a	2.00±0.67a	1.30±0.48a	2.20±0.63a
	Milled rice	3.50±0.53b	3.70±0.67b	4.10±0.32b	3.90±0.74a	3.70±0.67b	3.30±0.48b	3.40±0.52b	3.70±0.48b
	T_{5}	3.90±0.57b	3.90±0.74b	4.00±0.47b	4.00±0.67a	3.70±0.48b	3.50±0.53c	3.80±0.79b	4.00±0.47bc
	T_{11}	**3.90±0.74b**	**3.90±0.74b**	**4.10±0.32b**	**3.90±0.74a**	**3.70±0.67b**	**4.10±0.88c**	**3.40±0.52b**	**4.30±0.67c**
	T_{17}	3.70±0.48b	3.70±0.67b	4.10±0.32b	3.90±0.74a	3.70±0.67b	3.60±0.52bc	3.50±0.53b	4.20±0.63bc
	T_{23}	3.80±0.42b	3.70±0.67b	4.10±0.32b	4.10±0.57a□	3.70±0.67b	3.60±0.52bc	3.50±0.53b	3.90±0.32bc
KDML 105	Commercial (CPR)	2.10±0.88a	2.10±0.74a	3.40±0.52b	3.50±0.85ab	1.30±0.48a	2.00±0.67a	1.30±0.48a	2.20±0.63a
	Milled rice	4.60±0.52d	4.60±0.52c	3.50±0.85ab	3.90±0.74b	3.30±0.48bc	3.30±0.48b	3.50±0.53b	4.00±0.47d
	T_{4}	**3.80±0.42c**	**4.00±0.67b**	**3.40±0.70ab**	**4.00±0.47b**	**3.90±0.57c**	**3.50±0.71b**	**3.60±0.70b**	**3.40±0.52c**
	T_{10}	3.60±0.52c	3.70±0.48b	3.30±0.67ab	3.60±0.52ab	3.80±0.63c	3.60±0.52b	3.40±0.70b	3.20±0.42bc
	T_{16}	2.90±0.57b	3.60±0.52b	3.00±0.47ab	3.20±0.63a	3.10±0.74b	3.10±0.57b	3.40±0.52b	3.10±0.32bc
	T_{22}	2.60±0.70ab	3.50±0.53b	2.80±0.42a	3.00±0.82a	2.80±0.92b	3.00±0.67b	3.20±0.63b	2.80±0.42b□

*Values are mean +/- standard deviation determinations.
abc: The means with the same superscripts within each column are not significantly different ($P < 0.05$) by Duncan multiple range test.

3.3 Comparison Physicochemical of Properties of Different Varieties of Parboiled Brown Rice

The optimum conditions of parboiled brown rice from three different varieties were selected and their physicochemical properties were summarized and compared with milled rice and commercial parboiled paddy as in Table 6.

Table 6. Comparison of physicochemical properties of three varieties of parboiled brown rice at selected optimum condition and commercial parboiled paddy.

	HRY. (%)	Whiteness (%)	Color (b-value)	W.A g water/ g rice	Cooking time (min)	Hardness (N)	Vitamin E mg/100 g	Vitamin B_2 mg/100 g
Commercial parboiled paddy	75.77±0.94	36.30±0.44	12.53±0.12	2.03±0.02	25.00±0.00	52.68±1.55	Not appear	0.01±0.00
Chainat 1 (milled rice)	59.02±0.23	47.20±0.10	10.37±0.23	3.51±0.02	21.00±0.00	25.31±0.95	Not appear	0.006±0.00
Chainat 1 (T_{24})	70.37±0.52	41.90±0.70	11.33±0.47	2.20±0.05	23.00±0.00	48.70±0.44	Not appear	0.002±0.00
Supanburi 1 (milled rice)	58.29±0.05	47.20±0.10	9.30±0.50	3.42±0.07	23.00±0.00	35.46±3.58	Not appear	0.005±0.00
Supanburi 1(T_{11})	69.50±0.89	37.16±0.47	10.20±0.37	2.45±0.04	28.00±0.00	42.92±2.39	Not appear	0.003±0.00
KDML 105 (milled rice)	54.40±0.57	42.40±0.35	10.27±0.31	2.92±0.01	15.00±0.00	21.79±1.19	Not appear	0.008±0.00
KDML 105 (T_4)	66.18±0.20	37.63±0.15	10.37±0.15	2.05±0.05	14.00±0.00	17.95±0.65	Not appear	0.005±0.00

*Values are mean +/- standard deviation of three replications

It was found that decreased values of head rice yield, b-value, cooking time and hardness whereas increase in whiteness, water absorption and vitamin B2 of milled rice were obtained when compared to parboiled brown rice from all three rice varieties. Head rice yield of parboiled brown rice namely Chainat 1, Supanburi 1, and KDML 105 were at 70.37%, 69.50% and 66.18% respectively, whereas approximately 54-59% for milled rice of three varieties and 75% for commercial parboiled paddy. It was revealed that increase in head rice yield after parboiling process is observed because of increased tensile strength of kernel by starch granules inside the rice kernel after being gelatinized, thus resisting milling operation and reducing the grain breakage.

Whiteness of commercial parboiled paddy was at a mean value of 36.30%, whereas whiteness ranged from 37 to 41% and 42 to 47% for parboiled brown rice and milled rice of the three varieties, respectively. Results indicated that parboiled paddy gave lower whiteness. In addition, Supanburi 1 (milled rice) gave the lowest of b-value (9.30) while Chainat 1 and KDML 105 showed 10.37 and 10.27 respectively. Contrarily, parboiled brown rice showed greater b-value (10 to 11) than milled rice in all varieties. Moreover, commercial parboiled paddy had the highest b-value of 12.53. Therefore, using brown rice instead of paddy in parboiling process could improve whiteness value and yellowness value in the final product. The dark color of parboiled rice was caused by Maillard reaction between reducing sugar and amino acid activated by heat (Soponronnarit, 2006).

Parboiling process resulted in higher cooking time as shown in Table 6. Cooking time of brown rice in each variety increased in parboiling process while lower cooking time was for milled rice. Cooking time depended on several factors, not only parboiling process, but rice variety and storage time (Hogan, 1963). Another quality that related to cooking time was water absorption. Water absorption influenced volume of cooked rice. Parboiled brown rice showed that the average value of water absorption ranged from 2.05-2.45 g/g, while for milled rice it ranged in 2.92-3.42 g/g. The lowest value of 2.03 g/g occurred in commercial parboiled paddy.

The hardness value was of KDML 105 was low both for milled rice (18 N) and parboiled brown rice (22 N). The softer texture of cooked rice might be attributing to more water absorption during cooking. Furthermore, less extrusion force was noted because the texture was relatively more slippery – conforming the results reported by Sirisoontaralak (2006). Moreover, the results showed vitamin B2 for commercial parboiled paddy was to 0.01 mg/100 g for parboiled brown rice and 0.002 to 0.005 mg/100 g and 0.005-0.008 mg/100 g for milled rice of three varieties. Loss of vitamin B2 of parboiled brown rice was detected and its loss was greater than that of milled rice. Vitamin E was not detected in all parboiled rice and milled rice samples.

4. CONCLUSION

Three different varieties of Chainat 1, Supanburi 1 and KDML 105 brown rice were parboiled at different conditions of soaking and steaming. The parboiled brown rice gave better quality than commercial parboiled rice. Among the quality indicators (head rice yield, hardness, whiteness, color (b-value), water absorption, cooking time, vitamin E and vitamin B2), it was found that the parboiled brown rice presented intermediate values in all indicators between milled rice and commercial parboiled paddy. The optimum condition of parboiling for each rice variety was: for Chainat 1- initial temperature soaking of 80^{o} C, 2-4 h followed by steaming at 105^{o} C 15-20 min; for Supanburi 1- initial temperature soaking of 70^{o} C, 4 h followed with steaming 105^{o} C, 15-20 min; and for KDML 105- initial temperature soaking of 70^{o} C, 2 h and steaming 105^{o} C, 10-15 min. These conditions revealed suitable quality with highest acceptability scores from panelists.

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