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Research Article

Effect of multi-step soaking process on head rice yield of parboiled paddy

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ABSTRACT- Parboiling is one of the postharvest hydrothermal treatments applied on rough rice before drying and milling processes. This process has an important role in retaining the quality of rice kernels during storage, milling, and cooking. In this study, two rough rice cultivars, Tarom and Fuji Minory, were subjected to conventional and multi-step soaking for 90 minutes in water at temperatures of 50, 60 and 70 °C as a part of the parboiling process. Multi-step soaking was conducted in two and three steps followed by 15 minutes steaming at atmospheric pressure. Drying was performed by a fixed bed hot air dryer at 35 °C. The results indicated that in the conventional soaking, soaking temperature and steaming time affected the percentage of broken rice, bending strength and head rice yield (HRY) for both cultivars in a significant manner ($P<0.05$). The effect of soaking steps and steaming duration on the percentage of broken rice, bending strength, and HRY at temperature 70 °C were significant ($P<0.05$) for both rice cultivars. In overall, the multi-step soaking showed a significant positive impact on measured traits as compared to conventional soaking.

INTRODUCTION

Rice is a food staple for more than half of the world's population. Asia supplies 90% of the world's rice demand (Miah *et al.,* 2002; FAO, 2018). About 996 Mton rice (paddy) was produced all around the world in 2018 (FAO, 2018). One percent loss in the rice kernels while processing leads to about 9.96 Mton waste that is roughly four months of the nations' food supplies. Therefore, any scheme for preventing rice from being wasted during processing saves the rice production resources. Among different rice processing methods, parboiling has been introduced as a commercial method to reduce post-harvest losses of rice (Nawaz *et al.,* 2018).

Parboiling is a hydrothermal treatment that is performed on rough rice for improving rice kernel quality in three stages including soaking, steaming and drying (Buggenhout *et al.,* 2014). It has been shown that parboiling improves the quality of the milling, nutritional value and physical properties of rice kernels (Saleh *et al.,* 2018). Changing in physicochemical properties of rice during parboiling process resulting from gelatinization of starch in kernel provides better kernel stability and increases its hardness, as a result, higher percentage of head rice yield (HRY) is obtained during the milling, and fewer nutrients are lost while polishing (Bhattacharya, 2004). Many researchers have reported an increase in the coefficient of head rice conversion and reduction of broken rice by choosing the right method of parboiling (Lamberts *et al.,* 2008; Dooyum *et al.,* 2016; Yousaf *et al.,* 2017; Rahimi-Ajdadi *et al.,* 2018), however, reverse results will be obtained with inappropriate parboiling operations (Nassiri *et al.,* 2014). The main reason is due to very thin cracks that are created in kernels by residual stresses from unbalanced heat and mass transfer while processing.

Several studies have been conducted on the effects of temperature and soaking duration, amount and duration of applying temperature and pressure required for steaming, and the method of drying on quantitative and qualitative characteristics of rice kernels such as kernels breakage and color (Bello *et al.,* 2006; Lamberts *et al.,* 2008; Buggenhout *et al.,* 2014; Chungcharoen *et al.,* 2018). It has been reported that parboiling resulted in higher final tensile strength (about four to five times) and modulus of elasticity of rice grains (Saif *et al.,* 2004). Soaking is the most important operation of the parboiling because it provides the required moisture needed for starch swelling (Taghinezhad *et al.,* 2015). Parboiling efficiency of 95 % and milling quality of 91 % at 70 °C for three hours soaking have been reported as optimal conditions for parboiling (Imonigie *et al.,* (2017). The highest HRY and the lowest percentage of cracks were observed in the kernels steamed for 10 minutes after soaking followed by drying at 35 °C (Mahfeli *et al.,* 2014).

It was reported that intermittent drying method with tempering duration as well as stepwise drying decrease cracks development in kernels especially for heat-sensitive grains such as paddy. In this method, the moisture content is gently diffused from the center to the grain surface and reduces the moisture gradients inside the grain, thereby preventing cracks development (Maier and Bartosik, 2002; Sadeghi *et al.*, 2016; Nosrati *et al.*, 2021). Considering the large diversity in parboiling variables and their effects on HRY, further research on different conditions is of great importance, especially for popular cultivars that are highly susceptible to breakage because of thermal stresses. As different combinations of the related variables would provide different results, the present study was devoted to multi-step soaking operation. It has been shown that this type of operation has the potential for cracks development inside the kernels because of fast heat transfer and moisture migration inside the kernels (Nassiri and Etesami, 2015). Therefore, this study was aimed to investigate the effect of multi-step soaking on the physicals and mechanical properties of parboiled rice for two rough rice cultivars including Tarom and Fuji Minoty.

MATERIALS AND METHODS

Two rough rice (paddy) cultivars of Tarom (long grain) and Fuji Minory (short grain) were prepared from Mazandaran Province, Iran. The initial moisture contents of Tarom and Fuji Minory batches were measured by gravimetric method and found to be 12 and 13.5% (w.b.), respectively. Five hundred samples keeping in bags were stored at 4 °C in the refrigerator before experimental trials (Bello *et al.*, 2006). Samples were removed from the refrigerator, cleaned, and kept at room temperature for 12 hours before being treated. The ambient temperature during all tests was recorded to be 22 ± 5 °C.

Parboiling

Parboiling was performed by two soaking methods:

Conventional Soaking

Three sample batches were placed in wire net containers and soaked in warm water for 90 minutes at temperatures of 50, 60 and 70 °C. Sample containers were kept in a preset oven at the aforementioned temperatures to maintain the desired level of treatments. The same procedure for other samples was followed at 60 and 70 °C for 30 and 45 minutes.

Multi-step Soaking

Rough rice samples were soaked in multi-step (stepwise) process as below:

Some samples were soaked at 50 °C for 30 minutes, followed by soaking at 60 °C for 30 minutes and finally at 70 °C for the same duration as before (a total of 90 minutes).

Some Samples were soaked at 50 °C for 45 minutes, and then at 60 °C for 45 minutes (a total of 90 minutes).

Some Samples were soaked at 60 °C for 45 minutes, and then at 70 °C for the same duration (overall 90 minutes).

After the soaking process, samples were divided into two groups. The first group was steamed at atmospheric pressure for 15 minutes and the second group was not treated (Nassiri *et al.*, 2014). Finally, the samples were dried using a fixed bed hot air dryer at 35 °C to the final moisture content of 8.5% for Tarom and 10.5% for Fuji Minory (Nassiri and Etesami, 2015).

Physical and Mechanical Properties of Treated Rough Rice

Percentage of Cracked Rice

The percentage of cracked kernels was determined for three samples of 50 kernels using a crack-detector device consisting of a fluorescent lamp located at the bottom of a perforated plat (Jafari and Zare, 2017). Samples were randomly selected and husked carefully and cracked kernels were counted visually.

Strength of Rice Kernels

Due to the difficulty for the tensile test of rice kernels, a bending test was performed (Zhang *et al.*, 2005, Nassiri and Behzadian, 2014). Fracture force of kernels was measured using a compression testing machine (STM-20 SANTAM, Iran) equipped with three points test probe (Fig. 1).

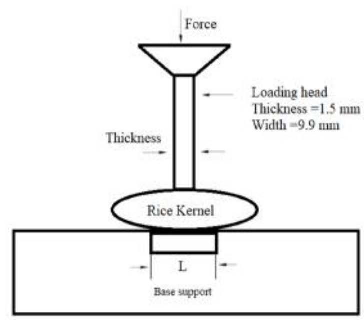

Fig. 1. Schematic diagram of the rig used for bending tests

The force was sensed with 50 kgf load cell (Bongshin manufacturing company, Taiwan, DBBP-50) at the rate of 0.5 mm/s (Yousaf *et al.*, 2017; Siebenmorgen and Qin, 2005). Fifty kernels from each cultivar were randomly selected and dehusked manually, and then subjected to loading. Rupture force (N) and elongation (distance, mm) for each test were recorded and data were stored in the software. The effect of the different cross-sectional areas of ruptured kernels was eliminated by converting the measured failure force to bending strength using the following equation:

$$\sigma = \frac{FL}{0.4\,wt^2}$$

where σ is bending stress (MPa), L is a span of rice kernel support (mm), F is the rupture force (N), w is the kernel width (mm), and t is the thickness of the kernel (mm).

Head Rice yield (HRY)

Rough rice samples were dehusked using a laboratory-scale rubber roll huller (Model THU-35A, Satake Engineering Co. Ltd., Tokyo, Japan). The HRY was calculated as a ratio of the weight of whole kernels to the weight of the rough rice in percentage (Rahimi-Ajdadi *et al.,* 2018; Tirawanichakul *et al.,* 2012). The term "head rice" denotes white kernels with 3/4 or more of the original kernel length (Aquerreta *et al.,* 2007). The measurements were performed in triplicates.

Statistical Analysis

Data collected from conventional soaking experiments (soaking temperature and steaming times as main factors) were analyzed based on factorial experiments in completely randomized design in triplicates. The means were compared using Duncan's post-test at a 5% probability level (SPSS 21 software). The results of the one-step soaking were used for the second tests to determine the effect of the soaking duration in the same way. Finally, the results of second trials were used to assess the effect of the stepwise soaking process. Stepwise parboiling data were analyzed by one-way ANOVA. The experiments flow chart is shown in Fig. 2.

RESULTS AND DISCUSSION

The percentage of cracked rice decreased significantly ($P<0.05$) with increasing soaking temperature for both cultivars. Initial cracks before parboiling were measured and found to be 59.1% and 55.4% for Tarom and Fuji Minory, respectively. There was a crack improvement of about 34.2% and 34.5% for Tarom and Fuji Minory cultivars, respectively (Table 1). The improvement refers to increase in moisture content at higher soaking temperature (Yousaf *et al.,* 2017). At the end of the steaming process, the maximum moisture content for Tarom and Fuji Minory cultivars was measured to be 35.6% and 39% (w.b.), respectively. These values provided the minimum moisture content required for proper gelatinization of starch in the sequential steaming process, which has been reported to be from 30 to 35% (Luh, 1991; Islam *et al.,* 2001; Parnsakhorn and Noomhorm, 2008; Sareepuang *et al.,* 2008). Successive steaming extensively reduced the amount of fissured kernels by 22.1% and 23.2% for Tarom and Fuji Minory cultivars, respectively (Table 1). It has been already shown that during steaming, the spread of water-soluble material in the grain that has been started since soaking, is continued and endosperm tissue takes a viscous state during the gelatinization process, so it prevents the cracking in kernels in subsequent processes (Nassiri *et al.,* 2016; Nasirahmadi *et al.,* 2014).

An increasing trend was observed for bending strength for both cultivars as soaking temperature and the steaming duration were increased (Table 1). Initial bending strength (before parboiling) of Tarom (13.5 MPa) and Fuji Minory (8.5 MPa), reached 16.8 MPa and 10.4 MPa at 70 °C soaking temperature, respectively. The improvement for Tarom and Fuji Minory were 24.4% and 23.4% respectively. As mentioned before, steaming improved bending strength by 17.8% and 15.3% for Tarom and Fuji Minory, respectively.

The main reason is the gelatinization of starch and consistency in the kernel structure. By considering the decreasing trend of cracks and increasing trend of bending strength, the HRY increased significantly when soaking temperature tended to move up to 70 °C ($P<0.05$) as shown in Table 1. The HRY of control was 44.8% for Tarom and 49.6% for Fuji Minory cultivar. Increasing of HRY was 30.4% and 25.2%, for Tarom and Fuji Minory, respectively, by the change in soaking temperature, and correspondingly 24.3% and 24.2% by the change in steaming duration.

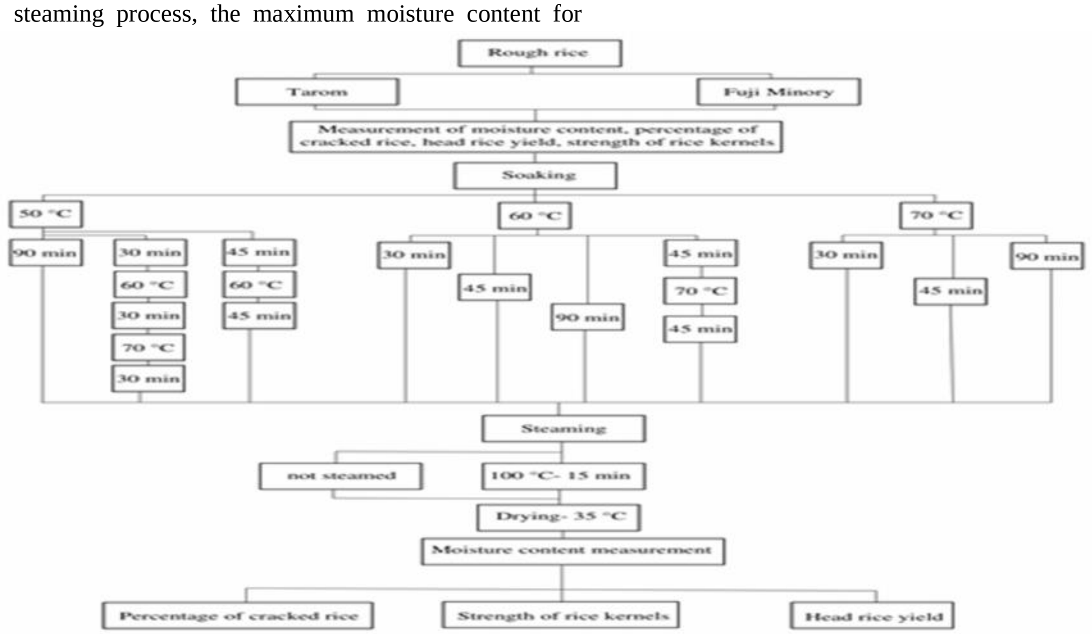

Fig. 2. Experiments flow chart

Table 1. Characteristics of parboiled rough rice treated by conventional (one step) soaking for 90 min

Characteristic	Variety	Soaking temperature (˚C)			Steaming time (min)	
		50	60	70	0	15
Crack (%)	Tarom	58.7 [a]	50.7 [b]	38.9 [c]	55.6 [A]	43.3 [B]
	Fuji Minory	56.4 [a]	51.3 [b]	36.3 [c]	54.3 [A]	41.7 [B]
Strength (MPa)	Tarom	14.5 [b]	14.6 [b]	16.8 [a]	14.7 [B]	15.9 [A]
	Fuji Minory	8.2 [c]	9.4 [b]	10.4 [a]	8.8 [B]	9.8 [A]
HRY (%)	Tarom	47.1 [b]	50.2 [a]	58.4 [a]	48.1 [B]	55.7 [A]
	Fuji Minory	49.3 [c]	54.4 [b]	62.1[a]	48.9 [B]	61.6 [A]

Different small or capital letters in each row show significant differences at 5% level of significance.
HRY: head rice yield

The main reason is the gelatinization of starch and consistency in the kernel structure. By considering the decreasing trend of cracks and increasing trend of bending strength, the HRY increased significantly when soaking temperature tended to move up to 70 °C (P <0.05) as shown in Table 1. The HRY of control was 44.8% for Tarom and 49.6% for Fuji Minory cultivar. Increasing of HRY was 30.4% and 25.2%, for Tarom and Fuji Minory, respectively, by the change in soaking temperature, and correspondingly 24.3% and 24.2% by the change in steaming duration.

As the soaking temperature of 50 °C did not provide a suitable temperature for gelatinization (Nassiri *et al.*, 2014; Taghinezhad *et al.*, 2016), characteristics of the samples at 60 °C and 70 °C, and different soaking durations followed by 15 minutes steaming were analyzed to select the appropriate soaking duration. For both cultivars, the percentage of cracked kernels decreased significantly with increase in temperature and soaking duration (Table 2).It has been already reported that the combination of soaking temperature and duration helped to gelatinize starch and ultimately fill the cracks (Miah *et al.*, 2002; Sirdhar and Manohar, 2003; Soponronnarit *et al.*, 2006; Himmelsbach *et al.*, 2008; Han and Lim, 2009; Newton *et al.*, 2011).

The strength of Tarom kernels did not change with the increase in soaking duration (from 30 to 90 min), whereas it had nearly 7.3% improvement for Fuji Minory cultivar. By considering the inverse relation between strength and the yield of white rice with crack percentage (Nguyen and Kunze, 1981; Nassiri *et al.*, 2014), HRY was significantly increased which was about 11.4% for Fuji Minory cultivar.

The HRY of Tarom and Fuji Minory cultivars for 90 min soaking at 70 °C followed by 15 min steaming increased to 61.5% and 67.8%, respectively. Overall, about 37.3% and 36.7% improvement in HRY were achieved. The reasons might be proper conditions of soaking duration and temperature which could have provided a stronger structure for rice kernels due to decomposition of the protein molecules and starch gelatinization which resulting in filling of cracks as an adhesion material. The findings of the present study were consistent with those studies conducted by Sareepuang *et al*, (2008) and Taghinezhad and Brenner (2017).

Multi-step Soaking

Considering the results of the previous section, two temperatures of 60 and 70 °C were selected for soaking the rough rice for 90 minutes followed by 15 minutes steaming. Comparison between conventional (one step) and multi-step soaking showed that there was no significant difference between the percentage of cracked kernels due to the number of soaking steps at both temperatures and for both cultivars. However, a decreasing trend was followed at both soaking temperatures (for both cultivars) by increasing the number of steps. The same as conventional (one step) soaking trend at 60 and 70 ^{0}C temperatures, a trend with the significant difference at 60 and 70 ^{o}C were followed for the two-steps soaking process (Fig. 3).

Ayamdoo *et al* (2013) and Taghinezhad *et al*, (2016) reported that the swelling and deformation of grain starch results in high strength in kernels after parboiling. In contrast with the results of crack, the strength of the kernels significantly increased with increasing in temperature as well as the soaking steps, so that the maximum mean strength of 19.4 MPa and 13 MPa was obtained in 3-step soaking at 70 °C for Tarom and Fuji Minory cultivars, respectively. As reported by researchers, it is obvious that parboiling breaks protein within the kernel and allows the starch to swell. Furthermore, parboiling restructures the kernel (Bhattacharya, 2004; Newton *et al.*, 2011; Ndindeng *et al.*, 2015). Therefore, the aforementioned phenomenon might be justifying the difference between the trends of diminishing cracks and the strength of the kernels (Fig. 4).

The trend of HRY versus soaking steps at different temperatures was quite upward (Fig. 5). A fraction of yield increasing was related to the increasing in the strength of the kernels as previously reported by some researchers (Kar *et al.*, 1999; Soponronnarit *et al.*, 2006; Nassiri and Etesami, 2015), and the others were related to the looseness of the bonds between the husk and kernel due to parboiling (Ayamdoo *et al.*, 2013).

By three-step soaking, the yield was increased about 50.7% and 49.2% compared with the control treatment for Tarom and Fuji Minory cultivars, respectively, and correspondingly 9.8% and 9.1% compared with the one-step soaking process (Fig. 4).

Table 2. Characteristics of parboiled rough rice by conventional (one step) soaking at different soaking durations followed by 15 min. steaming

		oaking temperature (˚C)		Steaming time (min)		
Characteristic	Variety	60	70	30	45	90
Crack (%)	Tarom	50.0 [a]	35.9 [b]	45.4 [A]	43.6 [AB]	39.8 [B]
	Fuji Minory	48.9 [a]	35.7 [b]	45.7 [A]	43.2 [AB]	38.0 [B]
Strength (MPa)	Tarom	15.2 [b]	17.2 [a]	16.1 [A]	16.3 [A]	16.2 [A]
	Fuji Minory	9.6 [b]	10.3 [a]	9.6 [B]	9.7 [B]	10.3 [A]
HRY (%)	Tarom	52.4 [b]	61.5 [a]	56.0 [A]	57.3 [A]	57.5 [A]
	Fuji Minory	57.7 [b]	67.8 [a]	57.9 [B]	60.2 [AB]	64.5 [A]

Different small or capital letters in each row show significant difference at 5% level of significance

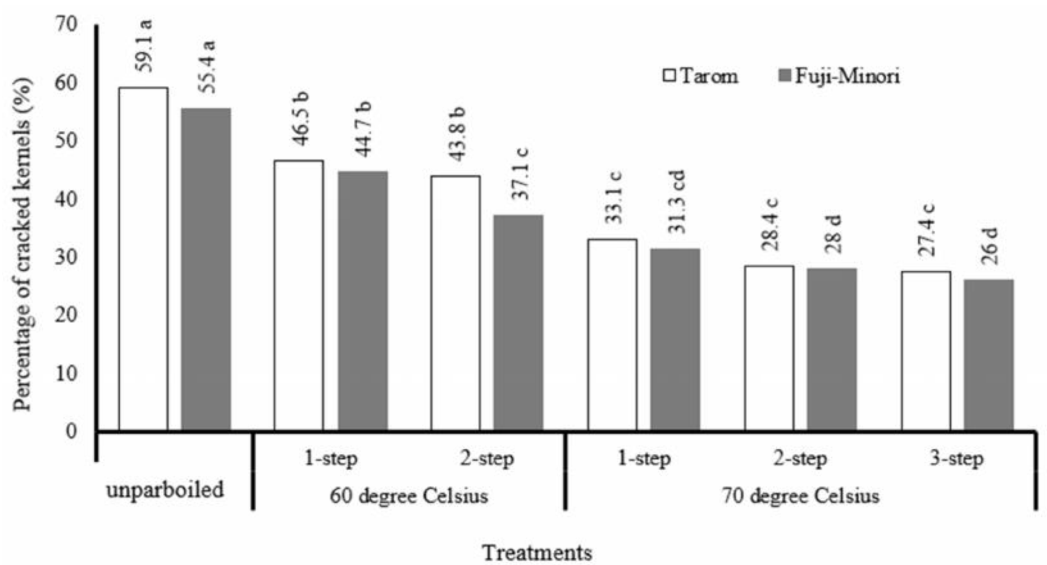

Fig. 3. Percentage of cracked kernels of parboiled rough rice for multi-step soaking methods at different temperatures in Tarom and Fuji Minory cultivars

Different letters for each cultivar show significant differences among means at 5% level of significance

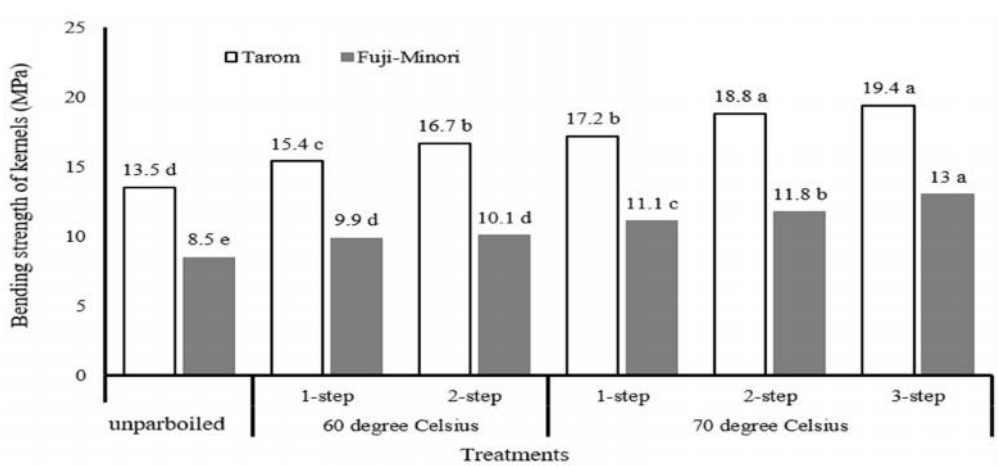

Fig. 4. Bending strength of parboiled rice for multi-step soaking methods at different temperatures in Tarom and Fuji Minory cultivars

Different letters for each cultivar show significant differences among means at 5% level of significance

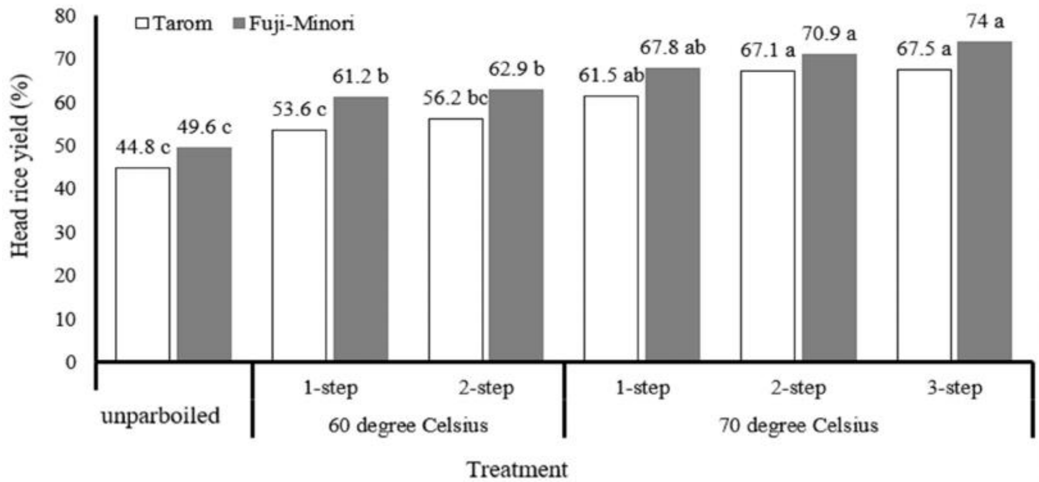

Fig. 5. Head rice yield of parboiled rice for multi-step soaking methods at different temperatures in Tarom and Fuji Minory cultivars

Different letters for each cultivar show significant differences among means at 5% level of significance

There was no significant difference between the yields in the case of soaking steps for both cultivars, however, considering the amount of extra yield (1-step soaking) and the amount of world rice production; these differences are noticeable at the commercial level. It is clear that this result should be reconsidered from specific energy or energy productivity point of view that has not been studied in the present work.

CONCLUSIONS

It was found that stepped soaking positively increased the strength of the kernels and head rice yield (HRY), and inversely reduced the percentage of cracked kernels. For one-step soaking maximum percentages of HRY for Tarom and Fuji Minory cultivars were 67.5% and 74.0%, respectively. For the three-step soaking treatment, the corresponding values for non-parboiled rice were 44.8% and 49.6%, respectively. Although from the amount of production point of view, there has been a positive increase in HRY, but in terms of other indices such as energy productivity, further researches are needed.

REFERENCES

Aquerreta, J., Iguaz, A., Arroqui, C., & Virseda, P. (2007). Effect of high temperature intermittent drying and tempering on rough rice quality. *Journal of Food Engineering*, 80(2), 611-618.

Ayamdoo, A. J., Demuyakor, B., Dogbe, W., Owusu, R., & Ofosu, M. A. (2013). Effect of varying parboiling conditions on physical qualities of Jasmine 85 and Nerica 14 rice varieties. *American Journal of Food Technology*, 8(1), 31-42.

Bello, M., Baeza, R., & Tolaba, M. P. (2006). Quality characteristics of milled and cooked rice affected by hydrothermal treatment. *Journal of Food Engineering*, 72 (2), 124-133.

Bhattacharya, K. R. (2004). Parboiling of rice. In. Champagne E. T. (Ed). *Rice: Chemistry and technology (3rd ed)*. (pp. 329-404) St Paul USA: American Association of Cereal Chemists.

Buggenhout, J., Brijs, K., Van Oevelen, J., & Delcour, J. A. (2014). Milling breakage susceptibility and mechanical properties of parboiled brown rice kernels. *LWT-Food Science and Technology*, 59 (1), 369-375.

Chungcharoen, T., Srisang, N., & Srisang, S. (2018). The study of quality attributes of parboiled rice during steaming process with revolved sieve. The 4th International Conference on Engineering, Applied Sciences and Technology (ICEAST 2018). July 4-7, Swissôtel Resort Phuket Patong Beach, Phuket, Thailand.

Dooyum, U. D., Woo, S. M., Hong, D. H., & Ha, Y. S. (2016). Optimization of parboiling conditions for enhanced Japonica rice milling. *Emirates Journal of Food and Agriculture*, 28(1), 764-771.

FAO. (2018). Crops. Retrieved from: http:// ww.fao.org/ faostat/en/#data/ QC/visualize.

Han, J. A., & Lim, S. T. (2009). Effect of presoaking on textural, thermal, and digestive properties of cooked brown rice. *Cereal Chemistry*, 86(1), 100-105.

Himmelsbach, D. S., Manful, J. T., & Coker, R. D. (2008). Changes in rice with variable temperature parboiling: Thermal and spectroscopic assessment. *Cereal Chemistry, 85*(3), 384-390.

Imonigie, P. S., Yusuf, K. A., & Atanda, E. O. (2017). Development of a temperature-controlled paddy rice parboiler. *American Journal of Mechanical and Materials Engineering*,1(1), 5-9.

Islam, M. R., Shimizu, N., & Kimura, T. (2001). Quality evaluation of parboiled rice with physical properties. *Food Science and Technology Research*, 7(1), 57-63.

Jafari, A., & Zare, D. (2017). Ultrasound-assisted fluidized bed drying of paddy: Energy consumption and rice quality aspects. *Drying Technology*, 35(7), 893-902.

Kar, N., Jain, R. K., & Srivastav, P. P. (1999). Parboiling of dehusked rice. *Journal of Food Engineering,* 39(1), 17-22.

Lamberts, L., Rombouts, I., Brijs, K., Gebruers, K., & Delcour, J. A. (2008). Impact of parboiling conditions on Maillard precursors and indicators in long-grain rice cultivars. *Food Chemistry,* 110(4), 916-922.

Luh, B. (1991). *Rice utilization (Vol. 2).* New York: Van Nostrand Reinhold.

Mahfeli, M., Qanbari, F., & Nassiri, S. M. (2014). Steaming time and drying temperature effect on broking force of parboiling. 8th National Congress on Agricultural Machinery Engineering (Biosystems) and Mechanization, Mashhad, 2014, Mashhad: Ferdowsi University of Mashhad.

Maier, D. E., & Bartosik, R. E. (2002). Optimizing grain dryer operations. Purdue University, Fact Sheet # 15.

Miah, M. A. K., Haque, A., Douglass, M. P., & Clarke, B. (2002). Parboiling of rice. Part I: Effect of hot soaking time on quality of milled rice. *International Journal of Food Science & Technology*, 37 (5), 527-537.

Nasirahmadi, A., Abbaspour-Fard, M. H., Emadi, B., & Khazaei, N. B. (2014). Modelling and analysis of compressive strength properties of parboiled paddy and milled rice. *International Agrophysics*, 28(1), 73-83.

Nassiri, S. M., & Behzadian, H. (2014). Brittle failure point of two Iranian rice cultivars. 12th International Conference on Energy and Mechanization in Agriculture. Turkey, September 3-6, Nevshehir.

Nassiri, S. M., & Etesami, S. M. (2015). Energy use efficiency of different drying methods for two rough rice cultivars. *Food Science and Technology,* 3(2), 23-28.

Nassiri, S. M., Shirzadifar, A. M., & Shojaei, J. (2014). Effect of parboiling failure strength of rice kernel. 8th National Congress on Agricultural Machinery Engineering (Biosystems) and Mechanization. Mashhad, Iran, January 29–31, 2014. Ferdowsi University of Mashhad. (In Persian).

Nassiri, S. M., Mahfeli, M., & Abolhasani, M. (2016). Effects of parboiling on some qualitative, physical and mechanical properties of two rough rice cultivars. *International Conference on Agricultural Engineering.* Aarhus, Denmark, June 26-29.

Nawaz, M. A., Fukai, S., Prakash, S., & Bhandari, B. (2018). Effect of soaking medium on the physicochemical properties of parboiled glutinous rice of selected Laotian cultivars. *International Journal of Food Properties,* 21(1), 1896-1910.

Ndindeng, S. A., Manful, J., Futakuchi, K., Mapiemfu-Lamare, D., Akoa-Etoa, J. M., Tang, E. N., & Moreira, J. (2015). Upgrading the quality of Africa's rice: a Novel artisanal parboiling technology for rice processors in sub-Saharan Africa. *Food Science & Nutrition,* 3(6), 557-568.

Newton, J., Wang, Y. J., & Mauromoustakos, A. (2011). Effects of cultivar and processing condition on physicochemical properties and starch fractions in Parboiled Rice. *Cereal Chemistry,* 88(4), 414-420.

Nguyen, C. N., & Kunze, O. R. (1981). Fissures related to post-drying treatments in rough rice. *Cereal chemistry,* 61(1), 63-68.

Nosrati, M., Zare, D., Nassiri, S. M., Chen, G., & Jafari, A. (2021). Experimental and numerical study of intermittent drying of rough rice in a combined FIR-dryer. *Drying Technology*, 1-14. https://doi.org/10.1080/07373937.2021.1898418.

Parnsakhorn, S., & Noomhorm, A. (2008). Changes in physicochemical properties of parboiled brown rice during heat treatment. *Agricultural Engineering International: The CIGR e-Journal*, 10, 1-20.

Rahimi-Ajdadi, F., Asli-Ardeh, E. A., & Ahmadi-Ara, A. (2018). Effect of varying parboiling conditions on head rice yield for common paddy varieties in Iran. *Acta Technologica Agriculturae,* 21(1), 1-7.

Sadeghi, M., Ghasemi, A., & Mireei, S. A. (2016). Rough rice stress fissuring with respect to conditions of drying and tempering processes. *Iran Biosystems Engineering,* 47(2), 269-279. (In Persian)

Saif, S. M. H., Suter, D., & Lan, Y. (2004). Effects of processing conditions and environmental exposure on the tensile properties of parboiled rice. *Biosystems Engineering,* 89(3), 321-330.

Saleh, M., Akash, M., & Ondier, G. (2018). Effects of temperature and soaking durations on the hydration kinetics of hybrid and pureline parboiled brown rice cultivars. *Journal of Food Measurement and Characterization*, 12(2), 1369-1377.

Sareepuang, K., Siriamornpun, S., Wiset, L., & Meeso, N. (2008). Effect of soaking temperature on physical, chemical and cooking properties of parboiled fragrant rice. *World Journal of Agricultural Sciences,* 4(4), 409-415.

Siebenmorgen, T. J., & Qin, G. (2005). Relating rice kernel breaking force distributions to milling quality. *Transactions of the ASAE,* 48(1), 223-228.

Soponronnarit, S., Nathakaranakule, A., Jirajindalert, A., & Taechapairoj, C. (2006). Parboiling brown rice using super-heated steam fluidization technique. *Journal of Food Engineering*, 75(3), 423-432.

Sirdhar, B. S., & Manohar, B. (2003). Hydration kinetics and energy analysis of parboiling Indica paddy. *Biosystems Engineering,* 85(2), 173-183.

Taghinezhad, E., & Brenner, T. (2017). Mathematical modeling of starch gelatinization and some quality properties of parboiled rice based on parboiling indicators using RSM. *Journal of Food Process Engineering,* 40(3), e12483.

Taghinezhad, E., Khoshtaghaza, M. H., Minaei, S., & Latifi, A. (2015). Effect of soaking temperature and steaming time on the quality of parboiled Iranian paddy rice. *International Journal of Food Engineering, 11*(4): 547-556.

Taghinezhad, E., Khoshtaghaza, M. H., Minaei, S., Suzuki, T., & Brenner, T. (2016). Relationship between degree of starch gelatinization and quality attributes of parboiled rice during steaming. *Rice Science*, 23(6), 339-344.

Tirawanichakul, S., Bualuang, O., & Tirawanichakul, Y. (2012). Study of drying kinetics and qualities of two parboiled rice varieties: Hot air convection and infrared irradiation. *Songklanakarin Journal of Science & Technology,* 34(5), 557-568.

Yousaf, K., Kunjie, C., Cairong, C., Abbas, A., Huang, Y., Arslan, C., & Xuejin, Z. (2017). The optimization and mathematical modeling of quality attributes of parboiled rice using a response surface method. *Journal of Food Quality,* ID 5960743, 1-13. https:// doi.org/ 10.1155/ 2017/ 5960743.

Zhang, Q., Yang, W., & Sun, Z. (2005). Mechanical properties of sound and fissured rice kernels and their implications for rice breakage. *Journal of Food Engineering,* 68(1), 65-72.

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اثر فرآیند خیساندن چند مرحله‌ای بر عملکرد برنج سالم شلتوک نیم پخت شده

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چکیده- نیم‌پخت کردن برنج یک از عملیات آبی-حرارتی شلتوک پیش از فرآیندهای خشک‌کردن و پوست‌کنی شلتوک است.. این عملیات نقش موثری در افزایش کیفیت دانه برنج هنگام ذخیره کردن، آسیاب کردن و پختن دارد. در این مطالعه برای انجام فرآیند نیم‌پخت کردن، از دو رقم شلتوک طارم و فوجی‌مینوری برای خیساندن معمولی و چندمرحله‌ای (پلکانی) به مدت ۹۰ دقیقه در آب با دماهای ۵۰، ۶۰ و ۷۰ درجه سلسیوس استفاده شد. خیساندن چندمرحله‌ای در دو و سه مرحله انجام شد و سپس نمونه‌ها به مدت ۱۵ دقیقه در فشار اتمسفر بخاردهی شدند. خشک کردن با استفاده از خشک‌کن هوای گرم با بستر ثابت با دمای ۳۵ درجه سلسیوس صورت گرفت. نتایج نشان داد در خیساندن به روش معمولی، اثر عامل‌های اصلی شامل دمای خیساندن و مدت زمان بخاردهی بر درصد ترک، استحکام خمشی و عملکرد برنج سالم هر دو رقم معنادار (P<۰/۰۵) بود. تاثیر مراحل خیساندن و مدت زمان بخاردهی بر درصد ترک، استحکام خمشی و عملکرد برنج سالم در دمای ۷۰ درجه سلسیوس در هر دو رقم معنادار بود. به‌طور کلی خیساندن چندمرحله‌ای در مقایسه با خیساندن معمولی تاثیر مثبت قابل توجهی بر صفات اندازه‌گیری شده داشت.