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Effects of Parboiling on Cooking Qualities of the Super Green Rice Variety Grown in Ethiopia

Melese Ageze Mihretu*

Department of Agricultural Engineering, Ethiopian Institute of Agricultural Research, Bahir Dar, Ethiopia
*soliana64@gmail.com; https://orcid.org/0000-0003-0940-2623

Abstract

As a result of the parboiling procedure, where the starch in the grains is gelatinized and solidified when cooled, the husk may be removed from the grain during shelling with minimal harm. Nutrient loss while cooking the grain is also prevented as a result of gelatinization. Water was absorbed by the grain's empty spaces during the gelatinization and retrogradation processes. Hence, the absorbed water and nutrient molecules can't leave after the starch has swelled up and cooled. In this study, the Selam rice variety was subjected to three factors: soaking temperatures of 40, 60, and 80ºC; soaking times of 6, 12, and 24 hours; and steaming times of 15, 25, and 35 minutes. The control group, non-parboiled rice, was also subjected to the full factorial design, which had a Completely Randomized Design (CRD) arrangement. The samples exposed to the highest time-temperature combinations showed variations in cooking time, swelling ratio, water uptake ratio, and percentage of chalkiness that were statistically significant ($P<0.05$). The cooking duration varied between 8.13 to 12.37 minutes, whereas the control took 9.28 minutes. The swelling ratio varied from 1.04 to 1.57, while the control was 1.26. The water uptake ratio values weren't statistically different, though. The color value difference varied from 8.95 to 19.57. When the soaking and steaming periods were extended to 24 hours and 35 minutes, respectively, for the 80ºC soaking temperature, the amount of chalkiness in the grains drastically dropped from 99.48% of the non-parboiled rice to just 0.33%. The highest soaking temperature (80ºC), soaking time (24 hours), and steaming time (35 minutes) were generally the best combinations for achieving the best cooking quality of parboiled rice.

Keywords: *chalkiness, cooking loss, cooking time, gelatinization, parboiling*

INTRODUCTION

Rice (*Oryza sativa*) belongs to cereal grain of the family *Poaceae*. For the vast majority of people on the planet, it is regarded as the main food crop (Vijay and Roy, 2018). According to IRRI, it is clear that rice cultivation has an impact on youth employment, food security, and poverty reduction. Rice is a staple food for people in many countries and is one of the most widely grown cereal crops worldwide (Rohman *et al.,* 2014). It is a grain with a diverse genetic makeup that is cultivated in hundreds of different kinds all over the world. One of the most significant food grains for humans has historically been rice due to its vast spread. Two-thirds of the world's population is fed this rice grain (Dhankhar, 2014). About 27% of the energy in low- and middle-income nations comes from rice. In all regions of the world, including Sub-Saharan Africa (SSA), it is one of the food commodities with the fastest rate of growth (Dawit and Tompson, 2020). The most significant crop in West Africa and the third-most significant crop in all of Africa is rice. It is consumed by more than 750 million people in sub-Saharan Africa (SSA) (EIAR, 2019). As opposed to other food crops, rice is ingested as a whole grain, making grain quality factors far more important. Around 618 million tons of rice were produced worldwide each year, of which 50% were converted into parboiled products (Rahimi-Ajdadi *et al.*, 2018).

Rice cultivation in Ethiopia most likely began when wild rice (*Oryza longistaminata*) was discovered in the wet, marshy areas of the Fogera (Amhara) and Gambella plains. In several regions of Ethiopia, rice output has grown consistently (EIAR, 2019). The entire land area has grown since the early 1970s, going from roughly 10,000 hectares in 2006 to about 50,000 ha in 2018. Before rice was introduced, the farmers in the Fogera Plain subsisted on pastoral farming and a modest amount of crop output (Tilahun *et al*., 2018). Gambella from 1973 to 1982, Pawe from 1985 to 1988, and the Fogera plain in the early 1980s were the first places where rice was introduced. The Fogera plain, however, has remained one of the top rice-producing regions among them, having shown a significant number of agricultural modifications related to rice production and its marketing.

According to Takele, (2017) and Dawit *et al*., (2018), Ethiopia is regarded as a significant rice-growing nation in Africa. More than 39 million hectares of Ethiopian land are ideal for growing rice. A little under 30 million hectares are upland, 3.7 million are irrigated, and the remaining area is used for lowland rice. From being the poorest farmers in the area to becoming the richest, the Fogera Plain's rice farmers have improved their quality of life. In the rice processing and marketing industry, private company owners have arisen and prospered (Dawit *et al*., 2018).

Even though rice is growing rapidly by area coverage and demand, the local rice varieties in Ethiopia have low physical and cooking quality attributes. Rice passes multiple steps of processing to be eaten during which it could be lost quantitatively and qualitatively due to milling at low moisture content, mal-operation of the polishing machine, and impurities with rice grain (EIAR, 2019). According to the study by Da, (2021), there is a very high loss of rice during de-hulling and polishing, when using poor-performance machines and unskilled operators. Parboiling emerged to improve the cooking and milling qualities of rice, where the process involves soaking, steaming, and drying (Ayenew *et al*., 2020). Thus, to solve this problem, parboiling technology has been introduced to Ethiopia recently to gelatinize the starch and harden the kernel.

Ethiopian rice varieties are not yet treated by the parboiling process. Rice consumers are asking the rice research and training center for technologies that could improve the cooking quality of rice. Rice processors in the South Gondar zone are adapting the parboiling process using the Africa Rice GEM parboiling technology. The processors were using firewood or electricity as a source of energy before the introduction of the Africa Rice GEM soaking and steaming apparatus. However, the GEM parboiling technology is easier and uses rice husk burning in a gasifier as a source of power. This study aimed to improve the rice cooking quality and reduce the percentage of chalkiness. The research was expected to enhance the livelihood of farmers and contribute to the betterment of the marketing system. Thus, the objectives of this study were to:

a) study the effect of soaking and steaming time-temperature interaction on the cooking time of parboiled rice,
b) study the effect of the time-temperature combination of soaking and steaming on the water uptake ratio of parboiled rice,
c) investigate the impact of the rice parboiling process on the swelling ratio of rice, and
d) study the effects of parboiling on the percentage of chalkiness and color of the parboiled rice

MATERIALS AND METHODS

Experimental Materials

Domestic lowland rice (*Selam*) variety of 81 kg was collected from Fogera National Rice Research and Training Center (FNRRTC), Ethiopian Agricultural Research Institute.

Experimental Plan

The experiment of parboiling was conducted with a full factorial design of having a completely randomized arrangement. It consisted of three factors with three levels. These are soaking temperatures of 40, 60, and 80°C; soaking time of 6, 12, and 24 hours and steaming time of 15, 25, and 35 minutes. Each treatment was carried out with three replications. The non-parboiled milled rice was the control that passed through the same processes except the parboiling. A control sample of 20-kg paddy was sun-dried (without parboiling) to 14% moisture content and was milled (Hasbullah *et al.,* 2017; EIAR, 2019).

Sample Preparation

Cleaning

According to Ndindeng *et al*. (2015) and Nambi *et al*. (2017), the cleaning of paddy was done based on the different physical properties such as size, density, weight, and properties of impurities. Both the experimental and control groups of collected rice grains were first cleaned very well using a hand-operated winnower. Impurities that were lighter than the paddy were removed by aspiration whereas those that could not be removed by the winnower were cleaned by handpicking.

Washing

The immature grains of the experimental groups were separated by floating in the water Ndindeng *et al*. (2015). The floated grains were removed and only the submerged ones were taken for the next process. Water-soluble dirt in the paddy was removed by washing it in water to prevent the entry of pollutants into the embryo during soaking and steaming. Then, the cleaned paddy was sun-dried and weighed.

Parboiling Process

Soaking

The soaking temperature was 40°C, the first 9 kg of paddy was soaked for 6 hours, the second 9 kg for 12 hours, and the third for 24 hours and left in ambient conditions till the time was up. The same procedures were followed for 60 and 80°C soaking temperatures. Each division of the sample was added into a soaking tank (which was made up of stainless steel, Inox 304), with plenty of water at the water-to-paddy rice ratio of 2:1 (Ndindeng *et al*. 2015; Hasbullah *et al*. 2017). The soaking temperatures and soaking time values used for this study were the medium values that scholars used (Ayamdoo *et al*., 2013; Bello *et al*., 2015; Ndindeng *et al*., 2015; Hasbullah *et al.,* 2017).

Steaming

Each of the samples was soaked for 6, 12, and 24 hours at a temperature of 40, 60, and 80°C divided into three equal parts having 3 kg each (Ndindeng *et al*., 2015). Each of the 3-kg samples was added to a perforated steaming apparatus made of stainless steel (Inox 304) one by one. The amount of water that was added to the steaming apparatus was a 1:2 ratio with the paddy. The paddy did not contact the water directly. It was steam-heated by the vapor released from the steaming tank. Samples from each soaking time were steamed for 15, 25, and 35 minutes of duration without removing the heat source. The steaming time values selected for this study were the medium values used by most scholars (Ndindeng *et al*., 2015; Hasbullah *et al*., 2017; Yerragopu and Palanimuthu, 2019).

Drying

The parboiled paddy was dried in the open sun by spreading it on a plastic sheet. It was continuously stirred to avoid over-drying on one side and to protect against the formation of internal cracks. The paddy dried up to 18% moisture content and was placed in the shade until it was slowly reduced to 14% (Ndindeng *et al.*, 2015; Hasan *et al.*, 2019). The moisture content level was checked every 15 minutes, using a rice grain moisture meter KETT J301, Japan (Ayenew *et al*. 2020).

Husking

The dried paddy was husked with a machine, SATAKE SB 2000, SATAKE Corporation, Hiroshima, Japan that was properly adjusted according to the technical manual, and brown rice was obtained (Nambi *et al*. (2017) and Ayenew *et al*. (2020).

Polishing

The brown rice was transferred into the polishing machine SATAKE SB 2000, Satake Corporation, Hiroshima, Japan to remove the bran from the endosperm. The properly adjusted rubber roll machine produced the polished white rice (Ayenew *et al*., 2020).

Determination of Physical Characteristics of Parboiled Rice

Moisture Content

The moisture content of the paddy was measured randomly using a digital rice moisture meter J301, Japan (Ayenew *et al.,* 2020; Paul *et al*., 2020; Bagchi *et al*., 2016) by taking a few grains from the sample. Measurements were taken after soaking, after steaming, during drying at different time intervals, and before husking or polishing to be sure of the 14%. Additionally, the moisture content of each sample was analyzed by the FOSS NIR Systems-6500 machine when the proximate composition was examined.

Percentage of chalkiness

Chalkiness is a level of low transparency of light through the grain. The number of chalky grains in the milled/polished rice was determined by a grain viewer magnifying lens (QUG/A2-SL, U.K.) with fluorescent light. Rice grain is said to be perfectly translucent when it allows light transmission through it. Otherwise, it's considered opaque or chalky. The percentage of chalkiness was determined by taking 10 g of parboiled milled rice from the samples. It was estimated by the following formula (Equation 1) (Ayenew *et al*., 2020; Jittanit and Angkaew, 2020; Sethy *et al.*, 2018).

$$\text{Chalkiness (\%)} = \left[\frac{\text{Weight of chalky grains}}{\text{Weight of sample grains}}\right] \times 100 \qquad (1)$$

Color

Color is an important criterion for the marketing value of parboiled rice. The whiteness color value of parboiled rice decreases to slightly darker (Taghinezhad *et al*., 2015). The overall color of the parboiled rice could be estimated using the formula given below (Equation 2); using Konica Minolta CM-5, Tokyo, Japan (Jittanit and Angkaew, 2020).

$$\Delta E = \sqrt{(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2} \qquad (2)$$

Where: L_2 stands for the brightness of parboiled rice, while L_1 represents the brightness of non-parboiled rice, a_2 is the red-green color component of parboiled rice, a_1 refers to the red-green component of non-parboiled rice color, b_2 refers to the yellow-blue color component of treated rice, and b_1 stands for the yellow-blue color component of non-parboiled rice (Nawaz *et al*., 2018). According to Taghinezhad *et al*. (2015), soaking at 65°C and steaming time of 4 min gives the highest values of desirable quality of parboiled rice, such as lightness.

Determination of Cooking Quality

Cooking time

According to Ndindeng *et al*. (2015) and Hasan *et al*. (2019), ten grams of milled rice from each sample were poured into 135 ml of vigorously boiled water in a 400 mL beaker and covered by a glass. After about 10 minutes of boiling, 10 grains were taken out one by one every minute with a perforated ladle. The removed grains were immediately pressed between 2 Petri dishes to know whether it was well cooked or not. The cooking continued until a minimum of the 10 grains had no opaque centers. The time taken for that to happen was recorded and considered the sample's optimum cooking time.

Water uptake ratio

The water uptake ratio is the capacity of the rice kernel to suck water when cooked. According to Thomas *et al*. (2013), Chavan *et al*. (2018), and Yerragopu and Palanimuthu (2019), the water uptake ratio (WUR) was estimated by taking 20 g of head rice and cooking in 200 mL of distilled water at 90ºC until there was no white core left in the grain. Then water uptake ratio was calculated mathematically by subtracting the weight of the uncooked kernel from the weight of the cooked kernel and dividing by the uncooked kernel using Equation 3.

$$\text{WUR} = \frac{\text{Weight of cooked} - \text{Weight of uncooked}}{\text{Weight of uncooked}} \qquad (3)$$

Swelling ratio

The swelling ratio (elongation ratio) is the extension of rice kernel length due to cooking and water uptake. It was estimated by randomly selecting 10 cooked rice kernels, measuring their lengths by digital Vernier Calliper, and dividing their mean value by the average length of 10 randomly selected raw rice grains measured by the same instrument (Thomas *et al*., 2013; Yerragopu and Palanimuthu, 2019) using Equation 4.

$$\text{Swelling ratio} = \frac{\text{Length of cooked kernel}}{\text{Length of raw kernels}} \quad (4)$$

Data Analysis

The collected data were statistically analyzed using Statistix-10 software. They were subjected to analysis of variance (ANOVA) to see the statistically significant differences due to the different parboiling treatments and the control (non-parboiled rice). The parameters considered were the percentage of broken rice, head rice yield, milling recovery, physicochemical properties, cooking quality, and nutritional qualities of rice. The statistically significant differences between sample means were analyzed by following a full factorial design arranged in CRD at a 5% level of significance.

Results And Discussions

Interaction Effects of Soaking Time, Soaking Temperature, and Steaming Time on the Quality Parameters of Parboiled Rice

Effects of pre-treatment temperature and soaking time on cooking quality

Table 1 presents data showing the interaction effects of soaking temperature and time on the cooking quality of parboiled rice. The interaction has a significant (P<0.05) effect on the cooking quality parameters except for the water uptake ratio. The cooking time ranged from 9.17 to 11.84 minutes, the longest being of samples soaked at 60ºC for 24 hours. On the other hand, the shortest cooking times (9.17 and 9.33 minutes) belonged to two samples soaked at 40 and 60ºC for 12 hr each. The interaction of the two factors appeared to have a balanced effect on the cooking time of parboiled rice and the values increased for most samples as compared to the control. This finding was corroborated by the report of Chavan *et al*. (2018) who showed that soaking at 85°C for three hours prolonged the cooking time of parboiled rice as compared to non-parboiled rice.

The swelling ratio data of parboiled rice showed significant (P<0.05) differences due to the interaction of the two factors. However, the data didn't show any trend with increasing soaking temperature and time. The swelling ratio values ranged from 1.16 to 1.38, the highest being of samples subjected to 40ºC for 6 hours. On the other hand the lowest values, 1.16, 1.17, and 1.22 mm/mm, with no statistical difference among them, were recorded for the combination of a soaking temperature of 60ºC and all three soaking times.

Chalkiness values were highest (14.78 and 12.56%) for samples subjected to the lowest soaking temperature (40ºC) and shorter soaking times of 6 and 12 hours, respectively. On the contrary, the four lowest chalkiness values (0.90, 1.11, 2.01, and 3.56) were of samples subjected to the longest soaking times regardless of soaking temperature. The data showed that the interaction effect of the two factors on chalkiness values was dominated by soaking time, i.e. short soaking time led to high values while long soaking times resulted in low values at each soaking temperature considered in the study. This indicated that the parboiling process conducted for longer soaking times resulted in a higher starch gelatinization rate and formed a translucent grain while short soaking time resulted in minimal gelatinization of the starch in the kernels thus some white spots remained inside the kernels.

The color values of the parboiled rice ranged from 11.57 for samples treated with a combination of 40ºC soaking temperature and 6 hours of soaking time to 18.26 for samples soaked at the highest temperature (80ºC) for the longest time (24 hours). The data showed increment due to increased soaking time for each soaking temperature with a similar increasing trend among the group of data of the different soaking temperatures exhibiting a balanced influence of the two factors on the color values in their interaction. The trend in the color data is inversely related to that of chalkiness data because the higher the chalkiness in the grains the lower the color difference between the parboiled and the non-parboiled rice grains. This is related to the level of starch gelatinization in the parboiled grain: higher gelatinization leads to lower chalkiness hence higher color difference from that of the non-parboiled grain.

Table 1: Effect of soaking temperature and soaking time on cooking qualities of rice

SkTp (ºC)	SkTm (hrs)	CT (min)	SR (mm/mm)	Chalkiness (%)	Color (ΔE)
40	6	$9.42^{f}±0.70$	$1.38^{a}±0.17$	$14.78^{a}±9.67$	$11.57^{g}±3.06$
	12	$9.17^{g}±0.41$	$1.27^{c}±0.16$	$12.56^{b}±9.02$	$12.64^{f}±2.17$
	24	$10.38^{e}±0.86$	$1.26^{c}±0.12$	$1.11^{g}±1.05$	$15.12^{d}±3.34$
60	6	$10.41^{e}±1.28$	$1.22^{cd}±0.15$	$10.78^{c}±5.24$	$13.72^{e}±2.85$
	12	$9.33^{fg}±1.04$	$1.16^{d}±0.14$	$6.56^{d}±5.50$	$15.12^{d}±1.59$
	24	$11.84^{a}±0.44$	$1.17^{d}±0.13$	$3.56^{e}±3.78$	$16.21^{c}±1.11$
80	6	$11.04^{c}±0.67$	$1.27^{c}±0.11$	$10.00^{c}±6.63$	$11.74^{g}±1.62$
	12	$11.30^{b}±1.60$	$1.28^{c}±0.11$	$2.01^{f}±2.11$	$17.66^{b}±1.75$
	24	$10.83^{d}±0.72$	$1.32^{b}±0.15$	$0.90^{g}±1.04$	$18.26^{a}±0.52$
Control		$9.28^{g}±0.09$	$1.26^{cd}±0.16$	$99.48^{a}±0.00$	$72.27^{a}±0.01$
CV (%)		2.12	4.05	13.32	1.44
$LSD_{0.05}$		0.21	0.05	0.87	0.2

Note: SkTp: soaking temperature, SkTm: soaking time, CT: cooking time (minutes), SR: swelling ratio (mm/mm), ΔE: color change between parboiled and non-parboiled rice, values are mean±SD

Effects of steaming time and soaking temperature on cooking quality

Table 2 presents the interaction effect of soaking temperature and steaming time on cooking qualities. Cooking quality parameters were significantly (P<0.05) affected by the interaction of the factors. Generally, the cooking time increased as both the soaking temperature and steaming times increased. The minimum cooking times (9.52 and 9.31 minutes) were recorded at the combinations of the lowest (40ºC) soaking temperature and shortest (15 and 25 minutes) steaming times. These values were statistically the same as the 9.28 minutes of the control sample. As the soaking temperature and steaming time rose, the cooking time of parboiled rice was extended. The interaction effect appeared to be balanced both factors exerting their influence on the cooking time. Ayenew *et al*. (2020) reported that the minimum cooking times of Ethiopian rice varieties were identified as 16-23 minutes for both *Ediget* and *Gumara* varieties when soaked at 40-80ºC for 10-50 minutes.

The interaction of soaking temperature and steaming time significantly (P<0.05) affected the water uptake ratio of parboiled rice. The highest values (1.46 and 1.62) were of samples subjected to the combination of the lowest (40ºC) soaking temperature and the two lower soaking times (15 and 25 minutes). At combinations of the higher soaking temperatures (60 and 80ºC) and the three steaming times the values significantly dropped in some cases with no significant difference from the 0.98 of the non-parboiled rice. These findings are supported by the work of Chavan *et al*., l (2018) who showed that soaking at 85°C and steaming for 40 minutes significantly (P<0.05) improved the water uptake ratio to 2.96%.

The swelling ratio of parboiled rice was also significantly (P<0.05) affected by the interaction of the two factors. The values ranged between 1.17 and 1.42 varying randomly. The non-parboiled rice exhibited a value of 1.26.

The chalkiness of parboiled rice was significantly affected (P<0.05) by the interaction of soaking temperature and steaming time. The highest value (99.48) was of the control non-parboiled sample. Of the parboiled rice, the highest value (15.22%) was of the combination of the lowest soaking temperature (40ºC) and shortest steaming time (15 minutes). The values decreased as the steaming time increased for all soaking temperatures and as the soaking temperature increased the chalkiness values dropped significantly. Thus the lowest value (0.68%) was of the combination of the highest (80ºC) soaking temperature and longest (35 min) steaming time.

The parboiling process affected the overall color difference of the rice samples. The highest overall color value (16.79) was determined for samples treated by the lowest soaking temperature (40ºC) and longest steaming time (35 minutes). The color difference value of parboiled rice in this study ranged from 10.54 to 16.79. Similar research work also showed that the color value for fresh parboiled rice samples was significantly (P<0.05) reduced to the non-parboiled rice (Nawaz *et al*., 2018).

Table 2: Effects of soaking temperature and steaming time on cooking quality parameters

SkTp (ºC)	SmTm (minutes)	CT (minutes)	WUR	Swelling Ratio	Chalkiness (%)	Color (ΔE)
40	15	9.52^{f}±0.29	1.46^{b}±0.37	1.32^{b}±0.15	15.22^{b}±10.72	12.01^{f}±1.44
	25	9.31^{f}±0.79	1.62^{a}± 0.30	1.42^{a}±0.15	11.78^{d}±8.06	10.54^{g}±1.52
	35	10.14^{d}±1.10	1.20^{cd}±0.19	1.17^{d}±0.05	1.44^{hi}±1.13	16.79^{b}±2.06
60	15	10.54^{c}±1.08	1.01^{e}± 0.15	1.18^{cd}±0.15	12.67^{c}±3.61	14.55^{e}± 0.18
	25	11.25^{ab}±1.40	1.13^{de}±0.14	1.21^{cd}±0.12	6.00^{f}±4.66	14.66^{e}±3.39
	35	9.79^{e}±1.47	1.12^{de}± 0.20	1.17^{d}±0.15	2.22^{h}±1.98	15.84^{d}±1.64
80	15	10.46^{c}±1.13	1.08^{de}±0.10	1.30^{b}±0.15	7.11^{e}±6.09	14.56^{e}± 3.88
	25	11.25^{b}±0.92	1.19^{cd}± 0.18	1.23^{c}±0.12	5.12^{g}±6.52	16.52^{c}± 2.37
	35	11.46^{a}± 0.95	1.26^{c}±0.16	1.34^{b}±0.07	0.68^{i}±0.99	16.57^{c}± 3.39
Control		9.28^{f}±0.09	0.98^{e}±1.02	1.26^{c}±0.16	99.48^{a}±0.00	72.27^{a}±0.01
CV (%)		2.12	11.34	4.05	13.32	1.44
$LSD_{0.05}$		0.21	0.13	0.05	0.87	0.2

Note: SkTp: soaking temperature, SmTm: steaming time, CT: cooking time, WUR: water uptake ratio, and ΔE: the color difference between parboiled and non-parboiled rice, values are in mean±SD, means represented by the same letter are not significant

Effects of soaking and steaming times on Cooking Quality

Table 3 presents the data showing the interaction effects of soaking time and steaming time on the cooking qualities of parboiled rice. All parameters of cooking quality were affected by the interaction of these two factors except the water uptake ratio, which did not exhibit statistically significant differences. The shortest cooking times of the parboiled rice were 9.76, 9.66, and 9.85 minutes for samples with a steaming time of 15 minutes combined with soaking times of 6 and 12 hours, respectively, and for the sample treated with a combination of 12 minutes of soaking and 35 minutes of steaming. On the other hand, the longest cooking times (11.09, 10.96, and 11.00 minutes with no statistical difference among them) were recorded for combinations of 24-hour soaking time with all three (15, 25, and 35 minutes) steaming times, respectively. The control sample (non-parboiled rice) had the shortest (9.28 minutes) cooking time. Thus parboiling process led to prolonged cooking time for the *selam* rice variety.

The interaction of soaking and steaming times significantly ($P<0.05$) affected the swelling ratio. The values ranged from 1.17-1.32 with the highest values being 1.27, 1.28, 29, and 1.32, the majority belonging to the 6 hours of soaking time combined with all three steaming times. All swelling ratios of the parboiled rice were significantly greater than the 0.98 of the control sample showing that parboiling improves swelling of rice granules.

Table 3: Interaction effects of soaking and steaming time on cooking quality parameters

SkTm	SmTm	CT (min)	SR	Chalkiness (%)	Color (ΔE)
6	15	$9.76^{d}\pm 0.53$	$1.27^{abc}\pm0.17$	$17.67^{b}\pm3.39$	$11.45^{h}\pm2.25$
	25	$10.56^{b}\pm1.55$	$1.32^{a}\pm0.21$	$15.33^{c}\pm4.00$	$10.84^{i}\pm2.01$
	35	$10.55^{b}\pm0.96$	$1.28^{abc}\pm0.07$	$2.56^{g}\pm1.81$	$14.75^{f}\pm2.07$
12	15	$9.66^{d}\pm0.61$	$1.26^{bc}\pm0.14$	$13.56^{d}\pm8.05$	$14.10^{g}\pm1.40$
	25	$10.29^{c}\pm1.58$	$1.29^{ab}\pm0.14$	$6.11^{e}\pm1.11$	$15.34^{e}\pm3.86$
	35	$9.85^{d}\pm1.97$	$1.17^{d}\pm0.13$	$1.46^{h}\pm0.50$	$15.98^{c}\pm2.36$
24	15	$11.09^{a}\pm1.08$	1.26bc±0.17	$3.78^{f}\pm1.20$	$15.57^{d}\pm2.28$
	25	$10.96^{a}\pm1.04$	$1.24^{bc}\pm0.12$	$1.46^{h}\pm0.37$	$15.54^{d}\pm2.38$
	35	$11.00^{a}\pm0.67$	$1.23^{c}\pm0.14$	$0.33^{i}\pm0.17$	$18.47^{b}\pm1.01$
Control		$9.28^{e}\pm0.09$	$0.98^{e}\pm1.02$	$99.48^{a}\pm0.16$	$72.27^{a}\pm0.00$
CV (%)		2.12	4.05	13.32	1.44
$LSD^{0.05}$		0.21	0.05	0.87	0.2

Note: SkTm: soaking time (hour), SmTm: steaming time (min), CT: cooking time in minutes, SR: swelling ratio, (ΔE): overall color, values are in mean±SD

The percentage of chalkiness was also significantly ($P<0.05$) affected by the interaction of soaking and steaming times. It decreased the values from 17.67 to 0.33% as the combinations of factors were increased from 6 hours and 15 minutes to 24 hours and 35 minutes. The effect of the interaction of the two factors on chalkiness is balanced such that a reduction of the values is observed both within each soaking time and across the three steaming times. Regarding the color difference between the parboiled and non-parboiled rice significant ($P<0.05$) differences were observed attributed to the interaction of the two factors. The largest difference (18.47) was of the sample subjected to the combination of largest soaking time (24 hr) and longest steaming time (35 minutes). It appeared that the influence of the highest steaming time within the interaction is visible resulting in the highest value at each of the three soaking times. However, the interaction of the two lower steaming times (15 and 25 minutes) and the three soaking times did not show a visible trend in color difference values. The color value of the non-parboiled rice is 72.27.

Interaction Effects of Heat Treatment, Soaking Time, and Steaming Time on Cooking Qualities of Parboiled Rice

Effects of parboiling on cooking time

Table 4 presents the three-factor interaction effects of pre-heating, soaking time, and steaming time on the cooking qualities of rice. At the lowest soaking temperature (40^{o}C) samples subjected to the highest soaking (24 hr) and steaming (25 and 35 minutes) times showed relatively longest cooking times of 10.14 and 11.29 minutes. A similar trend was observed for a soaking temperature of 60^{o}C with cooking times of 11.81, 12.29, and 11.43 minutes for 15, 25, and 35 minutes of steaming times whereas at 80^{o}C soaking, this trend was noted for combinations of 12 hr soaking time and 25 and 35 min steaming times. The rest of the combinations of the three factors did not show any clear trend in the cooking times. Some combinations of the three factors had even resulted in cooking times shorter than that of the non-parboiled rice. For instance, cooking times of 8.13, 8.68, 9.05, 9.10 and 9.17 minutes had been observed.

A similar study that was done by Ayenew *et al*. (2020) reported that the minimum cooking time of *Gumara* and *Ediget*, domestic rice varieties, was found to be 16 minutes, which were recorded at 40°C and 10 minutes, respectively.

Effects of parboiling on swelling ratio

The interaction of these three factors also significantly affected ($P<0.05$) the swelling ratio. The records did not show any clear trend with some of the values being lower than the 2.26 of non-parboiled rice used as control while others exhibited higher values even up to 1.41 and 1.54. A similar study showed that the value of the swelling ratio of the *Gumara* variety ranged from 2.46 at a temperature of 40°C and steaming time of 10 minutes to 3.00 recorded at a soaking temperature of 80°C and 50 minutes of steaming time (Ayenew *et al*., 2020).

It was also mentioned that the swelling ratio of parboiled rice varied depending on the parboiling conditions and varieties (Nawaz *et al*., 2018).

Effects of Parboiling on Chalkiness of Rice

The data showing the degree of chalkiness of rice are given in Table 8. The result indicated that the chalkiness value significantly ($P<0.05$) decreased with an increase in soaking temperature, soaking time, and steaming time. For a given soaking temperature as the soaking time increased, chalkiness values decreased, and for each soaking time the chalkiness values decreased as the steaming time increased. Thus all three factors have a strong and balanced influence on the chalkiness of the rice grains. Samples subjected to a combination of the lowest soaking temperature (40ºC), short soaking times of 6 and 12 minutes) and short steaming time (15 and 25 minutes) resulted in statistically the highest (20.33, 22.00, and 22.67%) chalkiness value. This is because the level of gelatinization of the starches in the grain under this treatment combination is low. Rice starch gelatinization temperature is between 55 and 79ºC. On the other hand, samples subjected to the highest soaking temperature (80ºC), longest soaking time, and longest steaming time resulted in the lowest chalkiness value of 0.33%. The steaming times, 15, 25, and 35 minutes have played a significant role in reducing the chalkiness values since thermal treatment is responsible for gelatinizing the starch inside the rice kernels in the presence of water. Gelatinized starch allows more light through it changing the rice grain into more translucent and thus less chalky. Combinations of different intermediate values of the soaking temperature, soaking time, and steaming time resulted in intermediate chalkiness values (Saha, et al., 2021).

Generally, parboiling decreased the percentage of chalkiness from 99.48% of the control non-parboiled sample to 0.33% of the parboiled one. A similar study on the *Narica-4* rice variety showed that the percentage of chalkiness was decreased from 100% (control) to 0.13% when soaked at 70°C heating temperature 50 minutes of steaming time, and 80°C soaking temperature and 50 minutes of steaming time (Ayenew *et al*., 2020). Another study also argued that the opaque white appearance seen on the rice grain of milled rice was highly reduced by the parboiling process (Oli *et al*., 2014).

Effects of parboiling on a color value

The overall color value (ΔE) of parboiled ranged from 8.95 to 19.54. The highest color difference was found at the lowest temperature (40°C), highest soaking (24 hours), and highest steaming times (35 minutes). The least color difference (8.95) was recorded at a soaking temperature of 40°C, soaking time of 6 hours, and steaming time of 25 minutes (Table 8). A similar study conducted in this regard stated that the color of parboiled rice was found to be 25.8, which was recorded at the soaking temperature and time, and steaming time combination of 67.7°C, 13 hours, and 18 minutes, respectively (Ogunbiyi *et al*., 2018). According to the study by Srisang and Chungcharoen (2019), the percentages of whiteness for the parboiled rice showed a decreasing trend compared to the non-parboiled rice.

Table 4: Effects of three-way interaction of parboiling factors on cooking quality

SkTp	SkTm	SmTm	Cooking time(min)	Swelling Ratio	Chalkiness (%)	Color (ΔE)
	6	15	$9.46^{hij}\pm0.15$	$1.38^{bc}\pm0.16$	$22.00^{b}\pm1.00$	$10.18^{o}\pm0.00$
	6	25	$8.69^{m}\pm0.53$	$1.54^{a}\pm0.12$	$20.33^{b}\pm1.53$	$8.95^{q}\pm0.03$
	6	35	$10.09^{fg}\pm0.45$	$1.21^{ghij}\pm0.05$	$2.00^{gh}\pm1.00$	$15.59^{h}\pm0.04$
	12	15	$9.37^{ijkl}\pm0.21$	$1.27^{b}\pm0.16$	$22.67^{b}\pm1.53$	$12.43^{m}\pm0.10$
40	12	25	$9.10^{kl}\pm0.52$	$1.41^{efg}\pm0.13$	$13.00^{de}\pm1.00$	$10.26^{o}\pm0.12$
	12	35	$9.05^{l}\pm0.53$	$1.14^{jk}\pm0.04$	$2.00^{gh}\pm1.00$	$15.25^{i}\pm0.04$
	24	15	$9.72^{hi}\pm0.43$	$1.29^{defg}\pm0.16$	$1.00^{h}\pm1.00$	$13.43^{l}\pm0.09$
	24	25	$10.14^{fg}\pm0.50$	$1.30^{defg}\pm0.12$	$2.00^{gh}\pm1.00$	$12.42^{m}\pm0.11$
	24	35	$11.29^{de}\pm0.77$	$1.18^{hijk}\pm0.04$	$0.33^{h}\pm0.58$	$19.54^{b}\pm0.07$
	6	15	$9.38^{ijkl}\pm0.22$	$1.17^{ijk}\pm0.16$	$16.00^{c}\pm1.00$	$14.43^{k}\pm0.10$
	6	25	$12.05^{ab}\pm0.49$	$1.14^{jk}\pm0.12$	$12.00^{e}\pm1.00$	$10.15^{o}\pm0.07$
	6	35	$9.82^{gh}\pm0.42$	$1.35^{bcde}\pm0.04$	$4.33^{g}\pm1.53$	$16.59^{g}\pm0.36$
	12	15	$10.45^{f}\pm0.14$	$1.24^{ghi}\pm0.17$	$13.67^{cde}\pm1.53$	$14.46^{jk}\pm0.04$
60	12	25	$9.43^{ijk}\pm0.12$	$1.22^{ghij}\pm0.12$	$4.00^{g}\pm1.00$	$17.20^{f}\pm0.01$
	12	35	$8.13^{n}\pm0.49$	$1.04^{l}\pm0.04$	$2.00^{gh}\pm1.00$	$13.70^{l}\pm0.05$
	24	15	$11.81^{b}\pm0.42$	$1.14^{jk}\pm0.17$	$8.33^{f}\pm1.53$	$14.78^{j}\pm0.09$
	24	25	$12.29^{a}\pm0.14$	$1.26^{fgh}\pm0.12$	$2.00^{gh}\pm1.00$	$16.64^{g}\pm0.03$
	24	35	$11.43^{cd}\pm0.17$	$1.11^{kl}\pm0.04$	$0.33^{h}\pm0.58$	$17.23^{f}\pm0.02$
	6	15	$10.45^{f}\pm0.11$	$1.26^{fg}\pm0.16$	$15.00^{cd}\pm1.00$	$9.73^{p}\pm0.08$
	6	25	$10.94^{f}\pm0.61$	$1.27^{efg}\pm0.13$	$13.67^{cde}\pm1.53$	$13.42^{l}\pm0.04$
	6	35	$11.74^{bc}\pm0.34$	$1.28^{defg}\pm0.05$	$1.33^{h}\pm1.53$	$12.05^{n}\pm0.04$
	12	15	$9.17^{jkl}\pm0.15$	1.27efg±0.16	$4.33^{g}\pm1.53$	$15.43^{hi}\pm0.09$
80	12	25	$12.35^{a}\pm0.23$	$1.24^{ghi}\pm0.12$	$1.33^{h}\pm1.53$	$18.56^{d}\pm0.01$
	12	35	$12.37^{a}\pm0.22$	$1.32^{cdef}\pm0.05$	$0.37^{h}\pm0.55$	$18.99^{c}\pm0.05$
	24	15	$11.75^{bc}\pm0.35$	$1.36^{bcd}\pm0.16$	$2.00^{gh}\pm1.00$	$18.52^{d}\pm0.01$
	24	25	$10.45^{f}\pm0.12$	$1.18^{hijk}\pm0.12$	$0.37^{h}\pm0.55$	$17.58^{e}\pm0.19$
	24	35	$10.28^{f}\pm0.05$	$1.41^{b}\pm0.05$	$0.33^{h}\pm0.58$	$18.67^{cd}\pm0.04$
	Control		$9.28^{jkl}\pm0.09$	$1.26^{fg}\pm0.16$	$99.48^{a}\pm0.00$	$72.27^{a}\pm0.01$
	CV (%)		3.59	9.90	11.01	1.22
	$LSD_{0.05}$		0.61	0.20	1.84	0.34

Note: SkTp: soaking temperature (ºC), SkTm: soaking time (hours), SmTm: steaming time (minutes), means represented by the same letter are not significant, values are in mean±SD

Conclusions

Rice is becoming one of the most valuable crop commodi-ties in Ethiopia. Rice can be consumed directly by cooking brown or white processed rice. But the domestic rice lacks the desired milling and cooking qualities. This study was launched to enhance the quality of rice kernels by examining treatment combinations during the parboiling process. The parboiling method enhanced the rice's physical characteristics. The length of parboiled milled rice increased to 5.33-6.84 mm compared to 4.57 mm for non-parboiled. Cooking factors included cooking duration, absorption of water ratio, and swelling ratio. The cooking time for par-boiled milled rice varied from 8.13 to 12.35 minutes. The swelling ratio was highest (1.54) at a soaking temperature of 40°C, a soaking period of six hours, and a steaming time of 25 minutes. The chalkiness of parboiled rice was signifi-cantly decreased to 0.33%. The color distinction between parboiled grains and non-treated rice grew with the duration and before treatment temperature of soaking and steaming.

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Authors contribution

Melese Ageze contributed to proposal writing, conducting the experiment, data collection, data analysis, and final paper writing. Getachew Neme contributed to proposal writing, revising, and interpretation. Solomon Abera contributed to methodology and design setup, final paper writing, and interpretation and approval.

Author Details

Melese Ageze Mihretu
E-mail: soliana64@gmail.com
https://orcid.org/0000-0003-0940-2623
Fogera National Rice Research and Training Center, Ethiopian Institute of Agricultural Research (EIAR), Bahir Dar, Ethiopia

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Data repository Statement

This manuscript is an original research study. We used original data as stated in the manuscript document. The data is available in our hosting institute document data base (the Ethiopian Institute Agricultural Research)

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