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Physical and cooking qualities of milled rice parboiled at optimal conditions for three selected Rice varieties in Nigeria

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Abstract
The physical and cooking characteristics of parboiled milled rice of three commonly grown rice varieties in Nigeria (FARO 44, FARO 52 and FARO 60) were investigated in this study. Rough rice samples of the three varieties were parboiled, dried and milled separately in a Central Composite Design (CCD) experiment with three factors at five levels using MINITAB 16 statistical software to provide for the optimisation of the paddy parboiling process. The physical and cooking qualities were thereafter evaluated using standard procedures. Results showed that the optimum Initial soaking temperature (IST), Soaking time (ST) and Final moisture content (FMC) for desirable physical qualities of FARO 44 rice variety are 70.3°C; 10 hours, 24 minutes and 15%. For FARO 52, the optimum values are 67.7°C; 13 hours, 18 minutes and 12.7% while for FARO 60, the optimum conditions are 76°C, 6 hours, 54 minutes and 15.2%. Parboiling at these optimum conditions resulted in high head rice yield in the three varieties with FARO 44 having the highest head rice yield and lowest percentage broken rice. However, FARO 52 has the highest grain hardness value of 74.7N while FARO 60 variety gave the highest lightness value of 27.71. For desirable cooking quality, the optimum IST, ST and FMC are 73.3°C; 16 hours, 18 minutes and 15.7% (wet basis) respectively for FARO 44 rice variety, 63.5°C, 7 hours and 12.9% (wet basis) for FARO 52 and 65.2°C, 13 hours 36 minutes and 11% for FARO 60 rice variety. The minimum cooking time for the three rice varieties is 15 minutes. The cooking time and elongation ratio of the milled rice of the three varieties however showed no significant difference though elongation ratio was lower in FARO 60 rice variety. The water uptake ratio of FARO 60 was 2.45, FARO 52, 2.19 and FARO 44, 1.77. For improved physical and cooking qualities, increased productivity and profitable paddy processing, it is recommended that rice processors should parboil the selected rice varieties at the optimised conditions obtained from this study.

Keywords: parboiled milled rice, rice varieties, physical properties, cooking properties, optimum parboiling condition

1. Introduction

Rice is a major staple food for millions of people in Sub-Saharan Africa, particularly, West Africa [1]. It is a strategic commodity in the Nigerian economy and can now be referred to as a policy crop in Nigeria. Rice can easily be prepared and consumed in various ways hence it is a regular item in the diets of Nigerians [2]. Rice is the fastest growing commodity in Nigeria's food basket and its demand has considerably increased over the years due to increase in population, urbanization and attendant shift in consumers' preference [3]. The status of rice in the average diet has also been transformed from being a luxury food item to that of a staple, taking the place of cassava and yam.

Nigeria being a multi-ethnic nation has a variety of food cultures and tastes, but its citizens still share in common, a preference for whole kernel, polished, parboiled long-grain rice, free from stone and other foreign matter, fluffy and tender when cooked [4, 5, 6]. The affinity and consumers' acceptability and choice of rice in Nigeria are greatly influenced by the eating and cooking qualities which are mainly controlled by the physicochemical and cooking properties of the rice grain [5, 7, 8]. This explains why imported parboiled rice is preferred against the locally processed rice by Nigerians as imported rice show more high consistency in terms of these quality attributes [7].

Rice parboiling is a major post-harvest handling processes of rice. It involves soaking the rough rice in hot or cold water over a period of time and steaming the soaked paddy to achieve gelatinization of the starch [9, 10, 11, 12, 13]. Parboiling causes the starch and protein in the endosperm to gelatinize and disintegrate respectively. The starch expands and fills the internal air spaces in the grains [9, 12]. Paddy parboiling results to more translucent grain kernels, higher milling yield, and increased swelling when cooked [12].

The commercial quality of milled rice is largely determined by its physical and cooking properties [8]. It is therefore very important to give attention to these vital intrinsic quality components of rice grains during postharvest rice processing so as to meet market demands at both local and international levels. The physical and cooking qualities of rice can be genetic or acquired properties and are required for specific uses by specific users [14]. Cooking qualities however are very essential to the household consumers who cook the rice grains for consumption. The qualities of parboiled milled rice depend mainly on the raw rice, parboiling factors/methods (defined by the soaking and steaming time) and the drying condition [12]. Parboiling at optimal conditions therefore will produce milled rice of desirable characteristics.

The objective of this study was therefore to determine the optimal parboiling conditions for FARO 44, FARO 52 and FARO 60 rice varieties and the physical and cooking

qualities of the parboiled milled rice.

2. Materials and Methods

The laboratory experiments were conducted at the Rice Postharvest Laboratory of the Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria. Three rice varieties, FARO 44, FARO 52 and FARO 60, which are commonly grown varieties in Nigeria, were used for this study. Rough rice samples were obtained from the rice Breeding Division of National Cereals Research Institute (NCRI), Badeggi, Nigeria. The experimental design, carried out with MINITAB 16 statistical software (Minitab Inc. USA, consisted of Central Composite Design (CCD) with three factors at five levels to provide for the optimisation of the paddy parboiling process. Twenty experimental runs calculated as 2k +2*k*+6 where k is the number of factors was carried out according to Khurram *et al*., 2017. [5] The experimental design is shown in Table 1. Optimisation of the parboiling factors was carried out and the quality characteristics (responses) at the optimized conditions were analysed.

2.1 Paddy treatment (soaking and steaming)

Rough rice (paddy) samples of three improved and high yielding varieties (FARO 44, FARO 52 and FARO 60) were obtained from the Breeding Research Division of the National Cereals Research Institute (NCRI), Baddegi, Nigeria. The samples were cleaned, dried and kept in clean bags at room temperature. The three varieties were parboiled separately at 3 soaking temperatures, 3 soaking time and uniformly steamed to achieve gelatinization according to Ogunbiyi *et al*. (2018) [16]. Soaking was carried out in plastic containers to reduce heat loss across the wall of the containers [9]. Soaked paddy was steamed with a 5kg per batch capacity laboratory rice paddy parboiler [17]. Wet parboiled paddy was uniformly dried in thin layer under shade to 3 moisture content levels (12, 13.5 and 15% wet basis) [9]. The experimental layout is shown in Table 1. Thin layer shade drying ensures uniform tempering of the drying paddy and prevents stress gradient in the grain [9]. This also prevents kernel breakage during milling. The dry parboiled paddy was dehusked, milled and graded using Test Husker THU35B, (Satake Corporation, Hiroshima, Japan), Test Mill TM05C, (Satake Corporation, Hiroshima, Japan) and Test Grader TRG05B (Satake Corporation, Hiroshima, Japan) respectively [16].

Table 1: Experimental Design

Run	Independent variables in coded form			Independent variables in their natural for		
	X_1	X_2	X_3	X_1	X_2	X_3
1	-1	-1	-1	65	8	12
2	1	-1	-1	75	8	12
3	-1	1	-1	65	16	12
4	1	1	-1	75	16	12
5	-1	-1	1	65	8	15
6	1	-1	1	75	8	15
7	-1	1	1	65	16	15
8	1	1	1	75	16	15
9	-1.68	0	0	61.59	12	13.5
10	+1.68	0	0	78.40	12	13.5
11	0	-1.68	0	70	5.27	13.5
12	0	+1.68	0	70	18.72	13.5
13	0	0	-1.68	70	12	10.98
14	0	0	+1.68	70	12	16.02
15	0	0	0	70	12	13.5
16	0	0	0	70	12	13.5
17	0	0	0	70	12	13.5
18	0	0	0	70	12	13.5
19	0	0	0	70	12	13.5
20	0	0	0	70	12	13.5

X_1 = Initial Soaking Temperature, X_2 = Soaking Time, X_3 = final moisture content

2.2 Laboratory analysis of samples

The physical properties (head rice yield, percentage broken rice, grain colour, and grain hardness) and cooking qualities (cooking time, elongation ratio, water uptake ratio) of the milled rice for each of the samples were evaluated using standard methods.

2.2.1 Physical properties

a. Head rice yield

This was determined using the method of Fofana *et al*. (2011). [14] Whole grains longer than three quarters of the whole kernel were separated automatically with Test Rice Grader TRG 05B (Satake Corporation, Hiroshima, Japan) and weighed. The head rice yield (HRY) was calculated as follows:

$$HRY = \frac{Weight\ of\ whole\ grain\ rice}{Weight\ of\ dry\ parboiled\ paddy} X\ 100 \quad (1)$$

b. Percentage broken rice

The broken rice grain was collected from rice grader and the percent broken rice was also determined in similar manner as the HRY as follows:

$$PBR = \frac{Weight\ of\ broken\ rice}{Weight\ of\ dry\ parboiled\ paddy}\ x\ 100 \quad (2)$$

c. Grain hardness

The hardness of five whole grains randomly selected from a sample was determined using Hardness Tester (Fujiwara

Seisakusho Ltd. Japan) according to Ogunbiyi, 2011 [5]. The samples were compressed vertically across its width on a flat plate until the grain ruptured. The force measured in Newton (N) at the bio yield point during compression was recorded as the hardness of the grain. The mean of five readings was recorded.

d. Grain colour

The colour of the grain was determined using a Rice Whiteness Tester C-600 (Kett Electric Laboratory, Japan). The equipment was first calibrated against a standard pure white plate of 85.5 whiteness value. The mean of three (3) different tests of a sample was recorded.

2.2.2 Cooking properties

The cooking qualities were determined using the method described by Parnsakhorn and Noomhorm (2008), Ogunbiyi (2011), Fofana *et al*. (2011) and Khurram *et al*. (2017) [5, 15. 15, 18].

a. Cooking time

Ten grams (10g) of whole milled rice sample was boiled in 135 ml distilled water in a 400 ml beaker. The rice was allowed to cook for 10 minutes after which 10 grains were taken out every 1 minute and pressed between two Petri dishes. The minimum cooking time was considered reached when at least 9 out of the 10 grains (90%) no longer had opaque centres. The mean values of three replicates were determined.

b. Grain elongation

The lengths (L_1) of 10 milled grains were measured with a digital caliper. The grains were then cooked in a wire-mesh cooking basket according to the time obtained above. The basket with the cooked grains was allowed to drain off for 2 minutes. The lengths (L_2) of the 10 cooked grains were again measured. Grain elongation (GE) was calculated as:

$$GE = \frac{Mean\ L_2}{Mean\ L_1} \quad (3)$$

c. Water uptake ratio

Ten grams (10g) of milled rice was placed in a wire-mesh cooking basket (initial weight of basket and rice = W_0) and put to cook for in excess boiling water in accordance with the cooking time earlier determined. The basket was withdrawn after cooking and the water was allowed to drain off for 2 minutes. The final weight of the basket with the cooked grain (W_1) was then determined. The water uptake ratio (WUR) was calculated as follows:

$$WUR = \frac{(W_1 - W_0)}{10} \quad (4)$$

2.3 Process Optimisation

Response surface regression analysis of the experimental data using MINITAB 16 statistical software (Minitab Inc. USA) was used to determine the optimum parboiling conditions for the selected rice varieties and correspondent regression equations for the responses were developed [19]. The responses (Yi) were expressed as functions of the parboiling factors (X_1, X_2 and X_k) as in Eq. (5).

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_I + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k} \sum_{i=1}^{k} \beta_{ij} X_i X_j + \varepsilon \quad (5)$$

Where:
Y = response variable,
β = constant and regression coefficients
k = number of process factors.

3. Results and Discussion

3.1 Physical properties

The minimum and maximum head rice yields of 67% and 71.3%, 65.9 % and 70.5%, 66.9% and 71.0% were recorded for FARO 44, FARO 52 and FARO 60 rice varieties respectively when parboiled under different parboiling conditions. The physical properties (Head rice yield, Percentage broken rice, Grain hardness and Colour) of parboiled milled rice of FARO 44, FARO 52 and FARO 60 rice varieties are presented in Table 2. For FARO 44, the highest value of HRY was recorded at experimental run 14 having Initial soaking temperature (X_1) = 70^0C, Soaking time (X_2) = 12hours and Final moisture content (X_3) = 16%, while the lowest value was recorded at experimental run 9 with conditions X_1 = 62^0C, X_2 = 12 Hours and X_3 = 13.5%. For FARO 52, the highest value of HRY was recorded at experimental run 12 with conditions X_1 = 70^0C, X_2 = 18.72 Hours and X_3 = 13.5%, while the lowest value was recorded at experimental run 6 with conditions X_1 = 75^0C, X_2 = 8 Hours and X_3 = 15%. The highest value of HRY for FARO 60 rice variety was recorded at experimental run 12 with conditions X1 = 70^0C, X_2 = 18.72 Hours and X_3 = 13.5%, while the lowest value was recorded at experimental run 6 with conditions X1 = 75^0C, X_2 = 8 Hours and X_3 = 15%.

Minimum percentage broken rice of 1.0%, 1.8% and 0.3 % were also observed for FARO 44, FARO 52 and FARO 60. These results are in agreement with Sanusi *et al*. (2017) [20] that reported that FARO 60 has the highest head rice yield and lowest percentage broken rice among the three rice varieties. The lower hardness value of 72.4N and high hardness value of 77.8N observed for FARO 44 and FARO 60 respectively in this study is also in agreement with Sanusi *et al.* (2017) [20]. This also explains the reduction in the percentage broken rice as harder grains withstand the friction effects of the paddy milling process more that softer grains [21].

3.2 Optimisation of the parboiling conditions for improved physical properties

The results of the optimization process of the experimental data for improved physical properties for the three rice varieties are presented in Figures 1, 2 and 3. Results showed that the optimum Initial soaking temperature (IST), Soaking time (ST) and Final moisture content (FMC) for desirable physical qualities of FARO 44 rice variety are 70.3°C; 10 hours, 24 minutes and 15%. For FARO 52, the optimum values are 67.7°C; 13 hours, 18 minutes and 12.7% while for FARO 60, the optimum conditions are 76°C, 6 hours, 54 minutes and 15.2%. The physical characteristics of the milled rice of the three rice varieties when parboiled at these optimum conditions are shown in Table 3. Parboiling the rice varieties at the optimized conditions improved all the tested physical quality when the lower limits of the experimental data are considered. The HRY for the three varieties are between 68.8 and 70.5%. This means that all

the three varieties have good HRY when parboiled at optimum conditions.

Table 2: Physical qualities of optimally parboiled milled rice

Response	Varieties		
	FARO 44	FARO 52	FARO 60
Head rice yield (%)	70.5	70	68.8
Broken rice ratio (%)	0.39	2.18	0.39
Grain hardness (N)	72.5	74.7	70
Grain colour	26.7	25.8	27.71

The colour of the grain was measured against a plain white background having a whiteness value of 85.5. [16] It means that the closer the whiteness value to 85.5, the lighter the colour of the grain. Whiteness value of the grain varies between 23 and 31 for the three rice varieties when parboiled at different parboiling conditions. The highest whiteness values for FARO 44, FARO 52 and FARO 60 rice varieties are 30.9, 27.6 and 28.9 respectively.

However, parboiling the paddy at the optimum conditions, the grain colour of the rice varieties reduced to 26.7, 25.8 and 27.7 respectively (Table. 4). The resulting darker colour is as a result of higher soaking temperature and longer soaking duration at the optimum condition compared to the lower limits of the experimental factors. High soaking temperature and soaking time been reported to inversely influence the colour of the parboiled milled grain. [9, 15] Variation in the grain colour between the varieties can also be due to varietal differences [22].

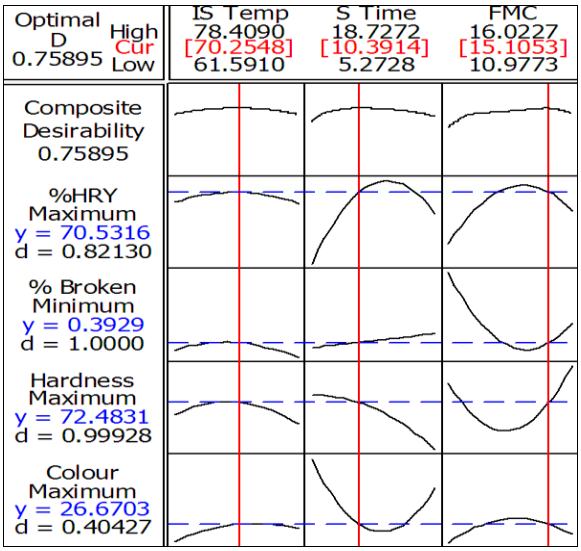

Fig 1: Optimisation plot for physical properties of FARO 44

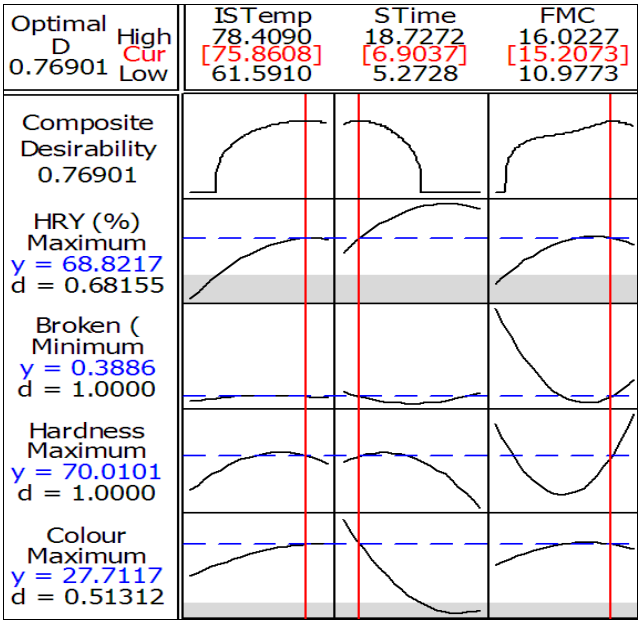

Fig 2: Optimisation plot for physical properties of FARO 52

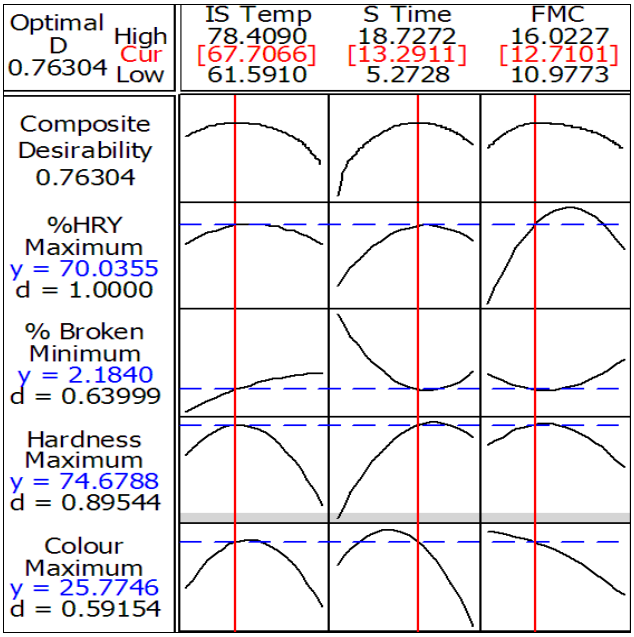

Fig 3: Optimisation plot for physical properties of FARO 60

3.3 Cooking Properties

The cooking properties (Cooking time, Elongation ratio and Water uptake ratio) of parboiled milled rice of FARO 44, FARO 52 and FARO 60 rice varieties are presented in Table 4.

3.4 Optimisation of the parboiling conditions for improved cooking properties

The results of the optimization process of the experimental data for desirable cooking properties for the three rice varieties are presented in Figures 4, 5 and 6. Results showed that the optimum Initial soaking temperature (IST), Soaking time (ST) and Final moisture content (FMC) for good cooking qualities of FARO 44 rice variety are 73.3°C; 16 hours, 18 minutes and 15.7% (wet basis) respectively; 63.5°C, 7 hours and 12.9% (wet basis) for FARO 52 and 65.2°C, 13 hours 36 minutes and 11% for FARO 60). The cooking qualities of the milled rice of the three rice varieties when parboiled at these optimum conditions are shown in Table 5.

Cooking time is a very important parameter of cooking quality of rice as it determines the amount of energy and fuel required to cook the rice [23]. Results from this study showed that cooking time for FARO 44 and FARO 52 are the same and varied between 15.3 and 18.3 minutes although these values occurred at different experimental runs with different parboiling conditions (Table 4) while the cooking time for FARO 60 rice variety was between 15 and 19 minutes. The higher cooking time for FARO 60 variety could be attributed to its higher amylose content and higher gelatinisation temperature (GT). FARO 60 is a variety with high GT and as such is expected to cook at longer time as amylose content affect the starch composition of the rice grain and also the cooking time [8]. However, upon optimisation of the parboiling process and parboiling the rice varieties at the optimum conditions shown in Figures 4, 5 and 6 for the three varieties, the cooking time for the three rice varieties was 15 minutes (Table 5).

Table 2: Physical properties of parboiled milled rice of the three rice varieties

Run	Independent variables in their natural form			FARO 44				FARO 52				FARO 60			
	X_1	X_2	X_3	HRY (%)	Hardness (N)	PBR (%)	Colour	HRY (%)	Hardness (N)	PBR (%)	Colour	HRY (%)	Hardness (N)	PBR (%)	Colour
1	65	8	12	68.60	54.90	1.40	29.90	68.30	60.80	2.10	25.50	66.95	64.2	0.30	26.50
2	75	8	12	68.90	55.50	1.10	30.90	67.90	62.40	3.30	24.80	68.01	69.4	0.40	27.20
3	65	16	12	70.40	68.60	1.30	24.50	68.60	77.70	2.50	24.00	67.63	64.1	0.40	28.90
4	75	16	12	69.80	72.00	1.20	25.60	69.10	58.90	2.40	24.40	69.60	70.9	0.30	25.80
5	65	8	15	69.70	51.60	1.50	28.70	68.30	54.80	3.00	25.60	67.11	66.6	0.30	26.80
6	75	8	15	68.40	57.80	2.60	29.00	65.90	62.10	3.00	26.50	69.28	69.7	0.30	26.60
7	65	16	15	70.80	67.90	1.40	26.00	70.90	68.60	2.50	24.20	67.83	60.5	0.70	27.00
8	75	16	15	70.80	71.20	1.10	25.20	70.80	63.70	2.10	23.90	69.80	67.7	0.40	25.30
9	61.59	12	13.5	67.00	58.80	1.70	26.50	69.90	60.10	1.90	25.30	66.30	60.7	0.40	27.40
10	78.40	12	13.5	69.10	72.50	1.10	26.50	68.80	63.10	2.20	25.30	70.98	65.0	0.40	25.70
11	70	5.27	13.5	68.20	49.00	2.30	29.30	67.00	56.50	3.40	26.10	66.90	65.1	0.70	28.30
12	70	18.72	13.5	68.40	60.10	1.50	25.80	70.50	69.20	1.80	26.00	70.90	59.3	0.50	28.20
13	70	12	10.98	68.80	66.00	1.00	28.10	67.20	64.70	2.50	27.60	67.20	77.8	2.50	26.40
14	70	12	16.02	71.30	60.80	1.50	23.80	67.90	68.00	2.30	26.70	69.93	73.0	0.40	26.30
15	70	12	13.5	70.80	64.40	1.60	26.10	69.80	73.80	2.30	24.30	69.93	65.6	0.40	26.70
16	70	12	13.5	70.70	67.30	1.70	25.90	70.40	73.80	2.30	24.30	69.93	65.6	0.30	26.70

X_1= Initial Soaking Temperature, X_2 = Soaking time (Hrs), and X_3 = Final moisture content (%), HRY = Head rice yield, PBR = Percent broken rice

Table 3: Cooking properties of parboiled milled rice of the three rice varieties

Run	Independent variables in their natural form			FARO 44			FARO 52			FARO 60		
	X_1	X_2	X_3	Cooking time (Min)	Elongation Ratio	Water Uptake Ratio	Cooking time (Min)	Elongation Ratio	Water Uptake Ratio	Cooking time (Min)	Elongation Ratio	Water Uptake Ratio
1	65	8	12	17	1.43	1.65	16	1.52	2.07	15.3	1.52	1.89
2	75	8	12	17.3	1.43	1.53	16	1.43	1.89	16	1.42	1.87
3	65	16	12	17.3	1.48	1.55	17	1.31	1.94	16	1.2	3.15
4	75	16	12	15.3	1.36	1.68	15.3	1.37	2.04	17.3	1.16	1.95
5	65	8	15	18.3	1.37	1.65	15.3	1.46	1.99	19	1.35	2.57
6	75	8	15	15.3	1.33	1.50	16	1.4	2.39	17.3	1.27	2.47
7	65	16	15	15.3	1.35	1.55	16	1.43	2.29	15	1.23	2.2
8	75	16	15	15.3	1.44	1.67	16	1.51	2.37	16	1.21	2.45
9	61.9	12	13.5	16	1.35	1.42	16	1.31	2.45	19	1.08	1.85
10	78.0	12	13.5	16	1.51	1.40	18.3	1.46	1.9	19	1.26	2.42
11	70	5.27	13.5	18.3	1.31	1.68	15	1.44	2.1	19	1.47	2.19
12	70	18.72	13.5	17	1.45	1.96	16.3	1.27	2.05	16.3	1.31	2.22
13	70	12	10.98	17	1.55	1.72	18.3	1.56	1.72	15.3	1.47	1.97
14	70	12	16.02	16	1.48	1.65	16.3	1.35	2.05	16	1.36	2.17
15	70	12	13.5	15.3	1.54	1.50	18	1.55	2.2	16	1.22	2.49
16	70	12	13.5	15.3	1.54	1.50	18	1.55	2.2	16	1.22	2.49

X_1= Initial Soaking Temperature, X_2 = Soaking time (Hrs), and X_3 = Final moisture content (%),

Grain elongation is considered a very good attribute of milled rice. The elongation ratio was between 1.31 and 1.55 for FARO 44; 1.27 and 1.56 for FARO 52; 1.08 and 1.52 for FARO 60 rice varieties when parboiled at different conditions. The elongation of the rice grain was 1.46, 1.48 and 1.32 for FARO 44, FARO 52 and FARO 60 respectively when parboiling was carried out at the optimum conditions. According to Danbaba *et al.* (2011) [4] and Thomas *et al.* (2013) [24], amylose content can significantly influence the elongation ratio. This also supports the results obtained when the varieties were parboiled at the optimised conditions as reported in Table 5.

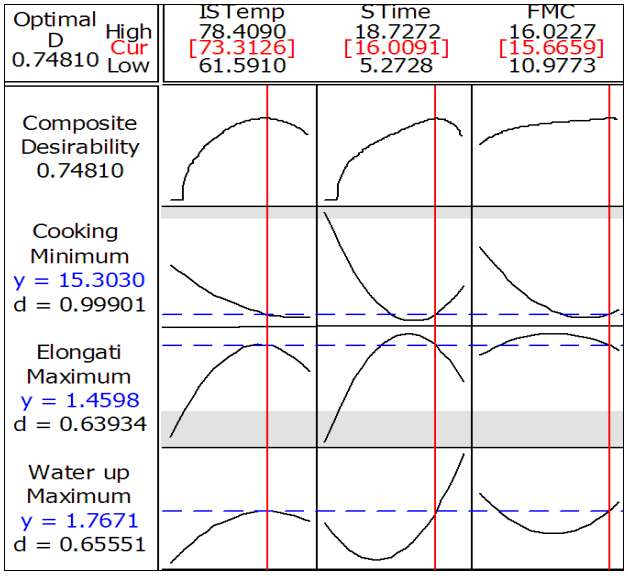

Fig 4: Optimisation plot for cooking properties of FARO 44

Maximum water uptake ratio for FARO 44, FARO 52 and FARO 60 are 1.96, 2.45 and 3.15. This means that FARO 60 rice variety has the highest water uptake ratio. This may be due to the high hardness value of the grain. High water uptake ratio of rice grain was reported to be directly related to its hardness [20].

The water uptake ratio of rice is very important as it affects the swelling capacity of rice which also is one of the characteristics that determine consumers' acceptability of milled rice [7].

The water uptake ratio of FARO 60 was higher than the other two varieties. This means that the rice grain will display a higher degree of swelling upon cooking without a considerable change in the grain length.

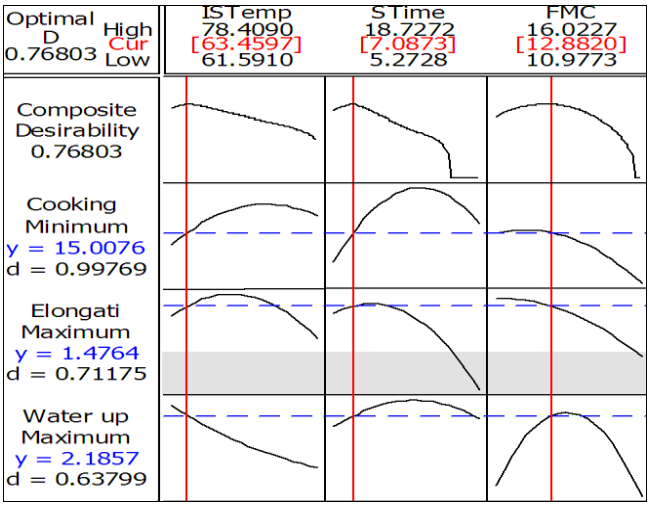

Fig 5: Optimisation plot for cooking properties of FARO 52

Table 5: Cooking qualities of optimally parboiled milled rice

Response	Varieties		
	FARO 44	**FARO 52**	**FARO 60**
Cooking time (Min)	15.3	15	15
Elongation ratio	1.46	1.48	1.32
Water uptake ratio	1.77	2.19	2.45

Conclusion

This optimum parboiling conditions for FARO 44, FARO 52 and FARO 60 rice varieties were determined in this study. The physical and cooking qualities of parboiled milled rice of these rice varieties were also evaluated. Parboiling the three rice varieties at the optimum conditions determined in this study produced milled rice of desirable physical and cooking qualities. The three widely grown varieties used in this study should be parboiled at the optimum conditions reported in this study for good physical and cooking qualities.

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