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Optimizing the Impacts of Process Factors on the Quality Indices of Multiple Rice (*Oryza sativa L.*) Varieties using Taguchi Technique

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Abstract

Inconsistence in rice quality during production can hinder its consumers' acceptability. This study investigated the impacts of process factors on the quality indices of five rice varieties using Taguchi technique. The processing factors [soaking temperature (65-75°C), soaking time (10-16 h), steaming time (20-30 min) and paddy moisture content (12-16%)] were interacted using Taguchi orthogonal array design of L9 (34). Paddy rice of FARO 44, FARO 52, FARO 60, FARO 61 and NERICA 8 were processed into polished parboiled rice using the conditions from the Taguchi interaction. The signal to noise ratio of Taguchi was used to evaluate the influence of processing conditions on the quality indices (milling recovery, head milled rice, white bellies, colour and lightness) using standard procedures. The optimum processing conditions for each rice variety was determined using composite desirability function (CDF) of numerical optimization. The impact of processing factors on the quality indices differs significantly on the rice variety. The milling recovery of the rice varieties ranges from 62.79 to 73.54%, head milled rice (59.81 to 71.63%), lightness value (22.92 -35.82), colour value (21.55 – 28.65) and white bellies (0.16 – 14.17%), respectively. However, the optimum processing conditions vary from one rice variety to the other with CDF that ranges from 0.82 - 0.96. Taguchi technique was successfully used to understand the impact of processing factors on the quality indices. The optimum processing conditions for achieving acceptable quality indices for the five rice varieties were predicted. This information would be useful in process optimization during rice processing.

Keywords: Processing factors; Quality indices; Rice varieties; Taguchi technique, Numerical optimization.

1.0 Introduction

Rice belongs to the genus *Oryza* with the most cultivated ones being *Oryza sativa* and *Oryza glaberrima*. *Oryza sativa* originated from Asia while *Oryza glaberrima* was from Africa (Oluwaseyi et al., 2016). Globally, more than three billion people consume rice as their staple food; in fact, it is categorised as energy food for people in developing countries (Sanusi and Akinoso, 2020). In the last decade, improved rice varieties with early maturity, high yielding potential, resistance to drought and better grain quality have been developed. For example, FARO 44, FARO 52, FARO 60, FARO 61 and NERICA 8 are improved paddy rice varieties with unique agronomical characteristics and high demand among rice processors in Nigeria (Oluwaseyi et al., 2016; Sanusi et al., 2020; Sanusi and Akinoso, 2020).

However, despite the improvement in rice varieties, inefficient processing conditions often cause huge loss in rice quality during processing (Danbaba et al., 2014; Kwofie and Ngadi, 2017; Sanusi and Akinoso, 2020). Although, it is challenging to precisely define rice quality indices as consumers' preferences vary from one geographical region to another (Cruz and Khush, 2002; Manful, 2010), rice processors still use some measurable parameters to grade their product quality. Such quality parameters include milling recovery, head milled rice, chalkiness or white bellies, colour, lightness and amylose content which is proportional to water uptake ratio and cooking time (Cruz and Khush, 2002; Manful, 2010; Sanusi et al., 2017). To minimize the significant losses in rice quality during processing and increase consumers' acceptability, there is need to extensively study and optimize the impacts of processing conditions on rice quality indices. In the same breadth, it is desirable to minimize experimental cost, timing and effort while we try to optimize the process conditions. Consequently, it is imperative to apply an optimization technique that could guarantee optimum quality yield with minimum experimental runs.

Conventional experimental design techniques have been found to have limitations when applied to industrial experimentation (Zhang et al., 2021). For this reason, Taguchi invented a method known as orthogonal array design which adds a new dimension to conventional experimental design (Dash et al., 2016). Taguchi Orthogonal Array (TAO) uses a special set of arrays that gives the minimum number of experiments with maximum information (Chen et al., 2011; Dash et al., 2016). According to Dutta and Narala (2021), the TAO approach offers recognition of the factors main effect in relatively few experiments and is also widely used in the manufacturing section for its robust optimization of process parameters. Sanusi et al. (2020) stated that orthogonal means balanced, separable or not mixed. In other words, the influence of an individual factor was not mixed up with the influence of other factors and was separated as a main effect of the said factor. Taguchi objective was to determine the optimum settings of input parameters, neglecting the variation caused by uncontrollable factors or noise factors (Gharaibeh and Pitarresi, 2019). Due to high competition in the food industry, companies have been forced to strategically increase their efficiency and reduce waste and this can be achieved by the introduction of techniques that can assist in reducing variability level and experimental cost in the food processing system.

Taguchi orthogonal array method has been applied in several food applications including fermentation, processing, microbiology, wastewater treatment and bioremediation (Rao et al., 2008). In fact, Singh (2012) opined that the Taguchi technique meets the current needs of the industry due to its shorter design cycle and improved design quality. Asadi and Norouzbeigi (2017) used Taguchi to develop a predictive model and optimize colloidal nano-silica from the production of expanded perlite. According to Mohapatra et al. (2017), Taguchi and artificial neural network can be used to model and optimise ultrasonic-assisted pretreatment of two

Pennisetum spp. Chen et al. (2011) reported that Taguchi is an effective technique that can be used to optimize factors in food science and engineering. Process factors of ready to eat peanut (Arachis hypogaea) were optimized by signal to noise ratio (Chandrasekar et al., 2015). Dash et al. (2016) applied an integrated Taguchi and response surface methodological approach for the optimization of a High performance Liquid Chromatographic (HPLC) method to determine glimepiride in a supersaturatable self-nano emulsifying formulation. Sanusi et al. (2020), applied the Taguchi technique to study the influence of process parameters on brown rice milling quality. Zhang et al. (2021) applied the Taguchi approach to simulate soil erosion experiment under different conditions. Optimization of extracted ginger oil in different drying conditions was also reported by Chen et al. (2011). Optimization of biodiesel from fish oil using ultrasonic energy was achieved via Taguchi orthogonal approach (Franco et al., 2014). Abdeen et al. (2021), optimised the performance of longitudinal axial flow of rice thresher using the Taguchi approach.

Despite the tremendous application of the Taguchi technique by different researchers, only a few studies have applied the technique in optimizing rice processing conditions. Therefore, this study was designed to evaluate the impacts of processing factors on quality indices of five rice varieties via the Taguchi technique.

2.0 Materials and Methods

2.1 Materials

Five Nigerian paddy rice varieties (FARO 44, FARO 52, FARO 60, FARO 61 and NERICA 8) were obtained from the breeding laboratory of the National Cereals Research Institute, Badeggi, Niger State, Nigeria. This research study was conducted at the grain quality laboratory of the National Cereal Research Institute, Nigeria.

2.2 Experimental design

In order to define the experimental range, a preliminary investigation was conducted by selecting some factors and levels based on information from the literature (Danbaba et al., 2014; Nasirahmadi et al., 2014). The important processing factors were soaking time, soaking temperature, steaming time and paddy moisture content. The average of the maximum and minimum values obtained from the preliminary experiment was used to design the main experiment using Taguchi experimental design. The Taguchi orthogonal array in Minitab®version 16 (Minitab, Inc. Coventry, UK) was used to design the main experiment. The experimental design has four (4) factors at three (3) levels given an array of L_9 (3^4) as shown in Table 1. Nine experimental runs were generated and were used to evaluate the effects of processing factors (soaking time, soaking temperature, steaming time and paddy moisture content) on the quality indices of polished parboiled rice.

2.3 Processing paddy rice into parboiled rice

Nine (9) samples of 1500 g of cleaned paddy rice of each variety were loosely tied in cloth bags. The samples were soaked by immersing in the water at temperatures of 65, 70 and 75°C for 10, 13 and 16 h based on the experimental design from Taguchi Orthogonal Array design. The desired temperature was monitored with the use of an infra-red thermometer (Model:FC-IR200, Finicare, China). The soaked samples were drained after each condition were met. Steaming was done using a fabricated rice parboiler for 20, 25 and 30 min. Steamed paddy grains with initial moisture content of 30% were dried using the shed drying method at a temperature of 28±4°C. The paddy moisture content was measured at intervals using a grain moisture meter (Model Riceter F506, Taiwan) till desired paddy moisture content of 12, 14 and 16% (wb) were achieved. Dried samples were packed in airtight plastic for moisture equilibration and hardness stabilization before being dehusked by a rice dehusker (Satake Engineering Corp., Model THU 35B, Tokyo, Japan), the resulting brown rice samples were graded into head rice and broken rice using IRRI rice grader and their mass measured using an electronic balance (GF-6000AND, Japan) of ± 0.1g accuracy. The whole/head brown rice obtained were polished for two minutes in a Satake grading testing mill (SE 1009, Satake Engineering Corp. Tokyo, Japan) and the polished rice was allowed to cool to room temperature (28 ± 4°C) and relative humidity (61.5 ± 5%) before separating into head milled rice and broken milled rice using IRRI rice grader. The polished rice samples were packed in paper bags and stored in a cupboard until further required for analysis.

2.4 Quality indices analysis

The milling recovery, head milled rice, white bellies, lightness value and colour value were were determined using Equation 1 to 4 as described by IRRI (1996), Sanusi et al. (2017) and Sanusi and Akinoso (2020) respectively.

Table 1. Taguchi experimental design parameters and levels L_9 (3^4)

Process factors	Unit	Level 1	Level 2	Level 3
Soaking time (S. T.)	h	10	13	16
Soaking temperature (S. Temp.)	°C	65	70	75
Steaming time (St. T.)	min	20	25	30
Paddy moisture content (P.M.C.)	%	12	14	16

$$MR = \frac{MMR}{MPR} \times 100 \quad (1)$$

where MR is the milling recovery, MMR is the mass of milled rice and MPR is the mass of paddy rice.

$$HMR = \frac{MHR}{MPR} \times 100 \quad (2)$$

where HMR is the head milled rice, MHR is the mass of head/whole milled rice and MPR is the mass of paddy rice.

$$WB = \frac{MWB}{MHR} \times 100 \quad (3)$$

where WB is the white bellies, MWB is the mass of the white bellies observed using International Rice Research Institute (IRRI) magnifier lens and MHR is the mass of the head milled rice (10 g).

The lightness and colour values of rice samples were measured by using Konica Minolta optics colour meter (Model CR-10, Tokyo Japan). The lightness value (L*) which varied from fully black to fully white (0-100) was used to measure rice samples lightness while the colour value was determined using Equation 4.

$$CV = \sqrt{(a^*)^2 + (b^*)^2} \quad (4)$$

where CV is the colour value, a* is the colour of the rice samples which ranges from red to green colour and b* is the colour of the rice samples which ranges from blue to yellow colour.

2.5 Taguchi analysis

The signal-to-noise (S/N) ratio (η, dB) represents quality characteristics for the observed data in the Taguchi analysis. The 'signal' represents the desired value and the 'noise' represents the undesired value, where the signal to noise ratio expresses the scatter around the desired value (Sanusi et al., 2020). The experimental results obtained from Table 1 were analysed using two types of S/N ratios namely: smaller-the-better quality characteristic (Equation 5) which was used to analyse less desirable quality indices (white bellies and colour value) while the larger-the-better (Equation 6), was used to analyse desirable quality indices (milling recovery, head milled rice and lightness value).

$$\frac{S}{N} = -10log\frac{1}{n}\left(\sum y^2\right) \quad (5)$$

$$\frac{S}{N} = -10log\frac{1}{n}\left(\sum \frac{1}{y^2}\right) \quad (6)$$

where S is the signal, N is the noise, y is the quality indices data, and n is the number of runs.

2.6 Numerical optimization

The numerical optimization is aimed to maximize the milling recovery, head milled rice and lightness value while white bellies and colour value are minimized within the ranges of the data obtained from the processing conditions of the five rice varieties. The experimental results obtained were used to predict the optimum conditions for FARO 44, FARO 52, FARO 60, FARO 61 and NERICA 8. Response Optimizer in Minitab Software version 16 was employed for the multi-objective optimization of the quality indices of the rice varieties. The composite desirability function (CDF) for the optimization was evaluated using Equation 7 as described by Sanusi and Akinoso (2020; 2021).

$$CDF = \left({d_1}^{u_1} \times {d_2}^{u_2} \times {d_3}^{u_3} \times {d_4}^{u_4} \times {d_5}^{u_5}\right)^{\frac{1}{\sum u_i}} \quad (7)$$

where d1-5 is the individual optimization desirability of milling recovery, head milled rice, white bellies, lightness value and colour value and ui is the important factors for each quality attribute

2.7 Statistical analysis

The Taguchi experimental runs were replicated twice and the mean values were analysed using Duncan's multiple-range test to compare the difference between means at a probability level p ≤ 0.05. SPSS® (Statistical Package for Social Sciences) version 20 Software USA was used to evaluate the Duncan's multiple-range test.

3.0 Results and Discussion

3.1 Impact of process factors on milling recovery

Table 2 depicts the impact of process factors on milling recovery using Taguchi technique. The milling recovery obtained for the rice varieties ranges from 62.79 to 73.54%. The result corroborates Akhter et al. (2015) findings, that milling recovery could range from 69.6 to 72.5%. The higher the S/N ratio the better the milling recovery showed that FARO 44 had the highest milling recovery (73.54%) at 70°C soaking temperature, 10 h soaking time, 25 min steaming time and at 16% paddy moisture content. The highest milling recovery in FARO 52 and FARO 61 were 71.47% and 71.76% at 75°C soaking temperature, 16 h soaking time, 25 min steaming time and 12% paddy moisture content. In FARO 60, 72.02% was the highest milling recovery at 65°C soaking temperature, 16 h soaking time, 30 min steaming time and 16% paddy moisture content while NERICA 8 had 70.87% as the highest milling recovery at 70°C soaking temperature, 13 h soaking time, 30 min steaming time and 12% paddy moisture content. The difference in the milling recovery of the rice varieties could be traced to the difference in their ability to withstand the polishing pressure of the rice polisher. Belay et al. (2013) reported variation in the milling recovery at different processing conditions.

The values of mean in the same columns with different superscript are significantly different at $p \leq 0.05$. MR denote milling recovery for FARO 44, FARO 52, FARO 60, FARO 61 and NERICA 8. S/N is the signal to noise ratio. S.Temp is the soaking temperature, S.T is the soaking time, St.T is the steaming time and P.M.C is the paddy moisture content.

The impact of the process factors on the milling recovery based on the larger the better of S/N ratio showed that soaking temperature had the most significant influence on the milling recovery of FARO 61, FARO 60, FARO 52 and FARO 44 while for NERICA 8, steaming time had the most significant influence on it. The variation observed in the influence of process factors on the rice varieties could be due to their intrinsic properties such as the level of the starch granules and the adequacy of the hydrothermal treatment at different processing conditions. Adequate hydrothermal treatment is expected to strengthening the kernel integrity and improves milling recovery.

Table 2. Impact of process factors on milling recovery using Taguchi technique

S. Temp. (°C)	S. T. (h)	St. T. (min)	P.M.C. (%)	MR 44 %	S/N	MR 52 %	S/N	MR 60 %	S/N	MR 61 %	S/N	MR 8 %	S/N
65.00	10.00	20.00	12.00	72.13^{b}	37.16	69.13^{b}	36.79	71.88^{a}	37.13	68.95^{d}	36.77	65.87^{e}	36.37
65.00	13.00	25.00	14.00	70.26^{d}	36.93	58.61^{d}	35.36	71.95^{a}	37.14	70.32^{b}	36.94	65.72^{e}	36.35
65.00	16.00	30.00	16.00	70.12^{d}	36.92	66.35^{c}	36.44	72.02^{a}	37.15	66.38^{cf}	36.44	69.00^{e}	36.78
70.00	10.00	25.00	16.00	73.54^{a}	37.33	71.23^{a}	37.05	70.30^{b}	36.94	64.55^{g}	36.20	69.64^{cb}	36.86
70.00	13.00	30.00	12.00	71.63^{bc}	37.10	71.18^{a}	37.05	71.15^{ab}	37.04	66.60^{f}	36.47	70.87^{a}	37.01
70.00	16.00	20.00	14.00	71.31^{bc}	37.06	68.86^{b}	36.76	67.79^{d}	36.62	67.97^{e}	36.65	62.79^{f}	35.96
75.00	10.00	30.00	14.00	70.02^{d}	36.90	70.72^{a}	36.99	69.33^{c}	36.82	69.42^{cd}	36.83	70.14^{ab}	36.92
75.00	13.00	20.00	16.00	70.98^{cd}	37.02	70.96^{a}	37.02	71.57^{a}	37.09	70.95^{ab}	37.02	68.74^{cd}	36.74
75.00	16.00	25.00	12.00	68.79^{e}	36.75	71.47^{a}	37.08	70.50^{b}	36.96	71.76^{a}	37.12	67.85^{d}	36.63

3.2 Impact of process factors on head milled rice

The amount of head milled rice recovered during a milling process is an important index that dictates the economic value of rice and its quality. The impact of process factors on the head milled rice is shown in Table 3. The head milled rice obtained ranges from 59.81 to 71.63% irrespective of the rice variety. The highest head milled rice observed in FARO 44 (71.63%) and FARO 52 (70.71%) was attained at 70°C soaking temperature, 10 h soaking time, 25 min steaming time and 16% paddy moisture content with S/N ratio of 37.10 and 36.99, respectively. No significant difference ($p \geq 0.05$) was observed in the head milled rice of some processing conditions in FARO 60. However, the highest S/N ratio was observed at 65°C soaking temperature, 10 h soaking time, 20 min steaming time and 12% paddy moisture content with 71.25% head milled rice. FARO 61 had the highest head milled rice (69.26%) when the S/N was 36.81 at 75°C soaking temperature, 16 h soaking time, 25 min steaming time and 12% paddy moisture content while in NERICA 8, the highest head milled rice (67.64%) was observed at 75°C soaking temperature, 10 h soaking time, 30 min steaming time and 14% paddy moisture content with S/N ratio of 36.73. The difference in the observed head milled rice of the rice varieties could be due to the variation in the level of starch gelatinization of the paddies of the rice varieties at different hydrothermal treatments. Starch gelatinization is expected to heal the internal fissures, eliminate fissures and chalkiness in paddy grains, thereby strengthening the grains against breakages that might occur during dehusking and polishing operations. Sanusi and Akinoso (2020) reported that during rice processing, the internal fissure of paddy grains are healed, resulting in higher head rice yield. Also, fissures and chalkiness have a negative impact on head milled rice (Buggenhout et al., 2013). The impact of processing factors on head milled rice based on the larger the better of signal to noise ratio showed that soaking temperature as the most significant influence on the head milled rice of FARO 61, FARO 60, FARO 52 and FARO 44 while steaming time had the most significant influence on the head milled rice of NERICA 8.

3.3 Impact of process factors on white bellies

Among the rice quality indices that signify loss to rice processor is the occurrence of white bellies. A high level of white bellies downgrades the physical appearance, lower milling recovery and it is a determinant of the market competitive price of any rice sample (Fofana et al., 2011; Sanusi and Akinoso, 2020). The impact of process factors on the white bellies using the Taguchi technique was shown in Table 4. The white bellies value ranges from 0.16% to 14.17% in the rice varieties. The lower the white bellies, the better the S/N ratio of Taguchi indicated that NERICA 8 had the lowest white bellies (1.12%) at 75°C soaking temperature, 16 h soaking time, 25 min steaming time and 12% paddy moisture content.

Table 3: Impact of process factors on head milled rice using Taguchi technique

S. Temp. (°C)	S. T. (h)	St. T. (min)	P.M.C. (%)	HMR 44 %	S/N	HMR 52 %	S/N	HMR 60 %	S/N	HMR 61 %	S/N	HMR 8 %	S/N
65.00	10.00	20.00	12.00	71.05[ab]	37.03	68.02[b]	36.65	71.25[a]	37.06	67.79[b]	36.62	59.81[e]	35.53
65.00	13.00	25.00	14.00	69.59[cd]	36.85	56.31[d]	35.01	70.97[a]	37.02	68.61[ab]	36.73	64.25[c]	36.16
65.00	16.00	30.00	16.00	69.69[cd]	36.86	65.92[c]	36.38	71.04[a]	37.03	63.79[f]	36.10	67.64[b]	36.60
70.00	10.00	25.00	16.00	71.63[a]	37.10	70.71[a]	36.99	70.04[bc]	36.91	61.02[e]	35.71	67.47[b]	36.58
70.00	13.00	30.00	12.00	71.04[ab]	37.03	70.38[a]	36.95	70.42[a]	36.95	64.80[d]	36.23	64.56[c]	36.20
70.00	16.00	20.00	14.00	70.75[ab]	36.99	68.18[b]	36.67	66.93[e]	36.51	64.48[de]	36.19	60.80[d]	35.68
75.00	10.00	30.00	14.00	69.31[d]	36.82	70.22[a]	36.93	68.43[d]	36.71	66.50[c]	36.46	68.61[a]	36.73
75.00	13.00	20.00	16.00	70.50[bc]	36.96	70.56[a]	36.97	68.65[d]	36.73	69.21[a]	36.80	54.62[f]	34.75
75.00	16.00	25.00	12.00	67.96[e]	36.64	69.79[a]	36.88	69.79[c]	36.88	69.26[a]	36.81	67.01[b]	36.52

Table 4: Impact of process factors on white bellies using Taguchi technique

S. Temp. (°C)	S. T. (h)	St. T. (min)	P.M.C. (%)	WB 44 %	S/N	WB 52 %	S/N	WB 60 %	S/N	WB 61 %	S/N	WB 8 %	S/N
65.00	10.00	20.00	12.00	2.15[a]	-6.66	0.56[de]	5.10	0.40[b]	8.02	1.94[g]	-27.66	10.68[b]	-20.57
65.00	13.00	25.00	14.00	1.33[b]	-2.49	3.94[a]	-11.91	0.39[b]	8.20	2.43[f]	-27.77	2.47[e]	-7.84
65.00	16.00	30.00	16.00	0.85[cd]	1.43	0.62[cde]	4.21	0.68[a]	3.37	4.07[d]	-27.61	1.75[g]	-4.86
70.00	10.00	25.00	16.00	1.99[a]	-5.97	0.97[b]	0.30	0.38[bc]	8.46	5.98[a]	-27.81	3.44[d]	-10.74
70.00	13.00	30.00	12.00	0.70[d]	3.06	0.76[c]	2.36	0.32[bc]	9.80	3.61[e]	-27.81	14.17[a]	-23.03
70.00	16.00	20.00	14.00	0.68[d]	3.38	0.98[b]	0.16	0.16[d]	16.10	5.41[b]	-27.36	3.60[d]	-11.13
75.00	10.00	30.00	14.00	0.90[cd]	0.93	0.72[cd]	2.85	0.23[cd]	12.62	4.78[c]	-28.16	2.10[f]	-6.44
75.00	13.00	20.00	16.00	0.74[cd]	2.59	0.51[e]	5.90	0.60[a]	4.45	1.93[g]	-26.59	9.84[cd]	-19.86
75.00	16.00	25.00	12.00	0.99[c]	0.11	1.12[b]	-0.95	0.40[b]	8.00	4.22[d]	-27.77	1.12[h]	-1.01

The values of mean in the same columns with different superscript are significantly different at $p \leq 0.05$. HMR and WB denote head milled rice and white bellies for FARO 44, FARO 52, FARO 60, FARO 61 and NERICA 8. S/N is the signal to noise ratio. S.Temp is the soaking temperature, S.T is the soaking time, St.T is the steaming time and P.M.C is the paddy moisture content.

For FARO 44, the lowest white bellies was 0.68% at 70°C soaking temperature, 16 h soaking time, 20 min steaming time and 14% paddy moisture content while the lowest white bellies (0.51%) for FARO 52 was observed at 75°C soaking temperature, 13 h soaking time, 20 min steaming time and 16% paddy moisture content. The lowest white bellies (1.93%) in FARO 61 was observed at 75°C soaking temperature, 13 h soaking time, 20 min steaming time and 16% paddy moisture content while for FARO 60 (0.16%) at 70°C soaking temperature, 16 h soaking time, 20 min steaming time and 14% paddy moisture content. White bellies disappeared upon parboiling and cooking and the result may have no direct effect on cooking and eating qualities. The difference in the white bellies at different processing conditions could be due to different degrees of starch gelatinization. The result is in agreement with Buggenhout et al. (2013, 2014), which reported that different soaking and steaming conditions have different degrees of starch gelatinization and levels on white bellies. Therefore, starch needs to be completely gelatinized to ensure the absence of white bellies and minimum fissured grain levels in the parboiled rice and consequence, a decreased milling breakage. The impact of processing factors on white bellies based on the lower the better signal to noise ratio showed that for FARO 44, soaking time had the most significant influence on white bellies while steaming time influences FARO 52 the most. The paddy moisture content had the most significant influence on FARO 60, soaking temperature on FARO 61 while soaking time for NERICA 8. The difference in the significant influence of the process factors could be due to the morphological properties of the rice varieties.

3.4 Impact of process factors on lightness value

In the purchase of quality rice, consumers' acceptability can be influence by a good lightening appearance. The production of lighter parboiled rice is the universal goal of any rice processor (Islam et al., 2004; Sanusi and Akinoso, 2020). Table 5 shows the impact of process factors on lightness values. The lightness values of the rice varieties after polishing were observed to varies from 22.92 – 35.82. The highest lightness value of 32.62, 32.64 and 32.64 were observed for FARO 44, FARO 52 and FARO 60 at 75°C soaking temperature, 10 h soaking time, 30 min steaming time and 14% paddy moisture content with the largest is better S/N ratio of 30.27, 30.28 and 30.28, respectively. The maximum lightness value in FARO 61 was 31.94 at 65°C soaking temperature, 13 h soaking time, 25 min steaming time and 14% paddy moisture content while the maximum lightness value (35.82) in NERICA 8 occurred at 75°C soaking temperature, 16 h soaking time, 25 min steaming time and 12% paddy moisture content and 70°C soaking temperature, 13 h soaking time, 30 min steaming time and 12% paddy moisture content with S/N ratio of 31.08. The impact of processing factors on the lightness values varied from one rice variety to another. In FARO 44 and NERICA 8, the soaking temperature had the most significant influence on the lightness value while steaming time was observed to influence FARO 52 and 60 the most. Soaking time had the most significant influence on FARO 61. Therefore, it is important to understand how the processing factors influence the lightness of the rice varieties, as this will aid in the proper selection of appropriate processing conditions for each rice variety.

3.5 Impact of process factors on colour value

Colour is an important quality attribute in the rice industry (Islam et al., 2004). Consumers frequently look at a rice sample and make a judgement decision based largely on overall appearance. The discolouration of rice is a negative effect of parboiling as discoloured parboiled rice losses market value and customer acceptability in most countries (Sanusi and Akinoso, 2020). Table 6 shows the impact of process factors on colour value. The colour value of the rice varieties ranges from 21.55 – 26.61.

The values of mean in the same columns with different superscript are significantly different at p≤0.05. LHT and CV denote lightness value and colour value for FARO 44, FARO 52, FARO 60, FARO 61 and NERICA 8. S/N is the signal to noise ratio. S.Temp is the soaking temperature, S.T is the soaking time, St.T is the steaming time and P.M.C is the paddy moisture content.

The colour change in the rice parboiling is mainly caused by enzymatic browning, non-enzymatic browning of the Maillard type and the diffusion of husk pigments in the endosperm during soaking and steaming (Leethanapanich et al., 2016; Sanusi and Akinoso, 2020). The minimum colour value of 21.55 was observed based on the smaller is better in FARO 44 at 65°C soaking temperature, 16 h soaking time, 30 min steaming time and 16% paddy moisture content while 22.38 was observed in FARO 52 and 60 at 65°C soaking temperature, 10 h soaking time, 20 min steaming time and 12% paddy moisture content. The minimum colour value of 21.36 was observed in FARO 61 at 75°C soaking temperature, 13 h soaking time, 20 min steaming time and 16% paddy moisture content while 26.61 was observed in NERICA 8, at 70°C soaking temperature, 16 h soaking time, 20 min steaming time and 14% paddy moisture content. The difference in the colour value among the rice varieties could be attributed to the difference in their genetic makeup and pigments. The impact of processing factors on colour value based on the smaller the better S/N ratio varied from one rice variety to another. Paddy moisture content had the most significant influence on FAR0 44 while soaking time was observed for FARO 52, FARO 60 and NERICA 8. Steaming time had the most significant influence on FARO 61. Ejebe et al. (2015) reported that the translucency of rice was different depending on the variety. The processing conditions during soaking and steaming are a precursor to Maillard reactions by decrease and/ or increase of the levels of the reducing sugars and free R-amino nitrogen containing proteins and peptides during paddy rice heating. The results also agreed with Parnsakhorn and Noomhorm (2008) who stated that parboiled paddy gave lower whiteness as compared to non-parboiled milled rice.

Table 5: Impact of process factors on lightness using Taguchi technique

S. Temp. (°C)	S. T. (h)	St. T. (min)	P.M.C. (%)	LHT 44	S/N	LHT 52	S/N	LHT 60	S/N	LHT 61	S/N	LHT 8	S/N
65.00	10.00	20.00	12.00	26.54^{e}	28.48	27.82^{d}	28.89	27.82^{c}	28.89	29.40^{bc}	36.62	22.92^{f}	27.20
65.00	13.00	25.00	14.00	25.88^{e}	28.26	31.36^{bc}	29.93	31.36^{c}	29.93	31.94^{a}	36.73	30.76^{c}	29.76
65.00	16.00	30.00	16.00	26.84^{e}	28.58	30.98^{bc}	29.82	30.98^{bc}	29.82	31.66^{a}	36.10	25.92^{e}	28.27
70.00	10.00	25.00	16.00	26.14^{e}	28.35	31.10^{bc}	29.86	31.10^{bc}	29.86	27.38^{e}	35.71	34.30^{b}	30.71
70.00	13.00	30.00	12.00	27.80^{d}	28.88	31.70^{ab}	30.02	31.70^{ab}	30.02	30.36^{b}	36.23	35.82^{a}	31.08
70.00	16.00	20.00	14.00	32.08^{ab}	30.12	30.38^{b}	29.65	30.38^{c}	29.65	28.24^{de}	36.19	29.46^{d}	29.38
75.00	10.00	30.00	14.00	32.62^{a}	30.27	32.64^{a}	30.28	32.64^{a}	30.28	29.44^{bc}	36.46	31.64^{c}	30.00
75.00	13.00	20.00	16.00	31.42^{b}	29.94	31.50^{b}	29.97	31.50^{b}	29.97	31.42^{a}	36.80	28.82^{d}	29.19
75.00	16.00	25.00	12.00	29.64^{c}	29.44	31.28^{bc}	29.91	31.28^{bc}	29.91	29.12^{cd}	36.81	35.82^{a}	31.08

Table 6: Impact of process factors on colour using Taguchi technique

S. Temp. (°C)	S. T. (h)	St. T. (min)	P.M.C. (%)	CV 44	S/N	CV 52	S/N	CV 60	S/N	CV 61	S/N	CV 8	S/N
65.00	10.00	20.00	12.00	23.67^{d}	-27.49	22.38^{d}	-27.00	22.38^{d}	-27.00	24.17^{bc}	-27.66	28.52^{b}	-29.10
65.00	13.00	25.00	14.00	25.06^{b}	-27.98	23.88^{bc}	-27.56	23.88^{bc}	-27.56	24.47^{b}	-27.77	28.65^{b}	-29.14
65.00	16.00	30.00	16.00	21.55^{e}	-26.67	23.40^{cd}	-27.38	23.40^{cd}	-27.38	24.01^{bc}	-27.61	28.19^{cb}	-29.00
70.00	10.00	25.00	16.00	24.44^{bcd}	-27.76	23.25^{cd}	-27.33	23.25^{cd}	-27.33	24.56^{b}	-27.81	28.52^{b}	-29.10
70.00	13.00	30.00	12.00	24.73^{bc}	-27.87	24.79^{b}	-27.89	24.79^{b}	-27.89	24.57^{b}	-27.81	27.37^{cd}	-28.75
70.00	16.00	20.00	14.00	24.35^{bcd}	-27.73	23.62^{c}	-27.47	23.62^{c}	-27.47	23.34^{c}	-27.36	26.61^{d}	-28.50
75.00	10.00	30.00	14.00	26.50^{a}	-28.46	23.16^{cd}	-27.30	23.16^{bcd}	-27.30	25.57^{a}	-28.16	32.03^{a}	-30.11
75.00	13.00	20.00	16.00	23.74^{cd}	-27.51	24.15^{bc}	-27.66	24.15^{bc}	-27.66	21.36^{d}	-26.59	28.46^{b}	-29.08
75.00	16.00	25.00	12.00	26.11^{a}	-28.34	26.97^{a}	-28.62	26.97^{a}	-28.62	24.45^{b}	-27.77	27.37^{c}	-28.75

3.6 Numerical optimization of the processing conditions of the rice varieties

Figure 1 shows the numerical optimization plot for the optimum processing conditions for (a) FARO 44, (b) FARO 52, (c) FARO 60, (d) FARO 61 and (e) NERICA 8 quality indices (milling recovery, head milled rice, lightness value, colour value and white bellies). From Figure 1a, the composite desirability function is 0.91 and the optimum processing conditions for FARO 44 was attained at approximately 65°C soaking temperature, 12 h, soaking time, 30 min steaming time and 16% paddy moisture content with predicted quality indices values of 73.36%, 71.87%, 31.42, 22.59 and 0.68 for milling recovery, head milled rice, lightness value, colour value and white bellies. Figure 1b, shows that the composite desirability function is 0.96 for the quality indices of FARO 52 and the optimum processing conditions was attained at approximately 65°C soaking temperature, 12 h, soaking time, 30 min steaming time and 15% paddy moisture content with predicted quality indices values of 71.82%, 70.71%, 31.78, 22.39 and 0.45 for milling recovery, head milled rice, lightness value, colour value and white bellies. Figure 1c, shows that the composite desirability function is 0.82 for the quality indices of FARO 60 and the optimum processing conditions for the quality indices was attained at approximately 65°C soaking temperature, 11 h, soaking time, 30 min steaming time and 14% paddy moisture content with predicted quality indices values of 71.64%, 70.84%, 31.41, 22.49 and 0.36 for milling recovery, head milled rice, lightness value, colour value and white bellies. Figure 1d, shows that the composite desirability function is 0.95 for the quality indices of FARO 61 and the optimum processing conditions was attained at approximately 65°C soaking temperature, 11 h, soaking time, 30 min steaming time and 15% paddy moisture content with predicted quality indices values of 71.76%, 70.89%, 31.36, 21.94 and 0.45 for milling recovery, head milled rice, lightness value, colour value and white bellies. Figure 1e, shows that the composite desirability function is 0.96 for the quality indices of NERICA 8 and the optimum processing conditions was attained at approximately 75°C soaking temperature, 13 h, soaking time, 30 min steaming time and 15% paddy moisture content with predicted quality indices values of 70.87%, 68.79%, 33.68, 24.47 and 0.46 for milling recovery, head milled rice, lightness value, colour value and white bellies. According to Sanusi and Akinoso (2021), the closer the CDF is to unity, the more the accuracy of the predicted optimum conditions. Therefore, the CDF of the predicted optimum processing conditions were within the acceptable range. This numerical optimization clearly shows that attainment of desirable quality indices is a function of combination of right processing conditions. In addition, the optimum processing conditions of rice differs based on the rice variety.

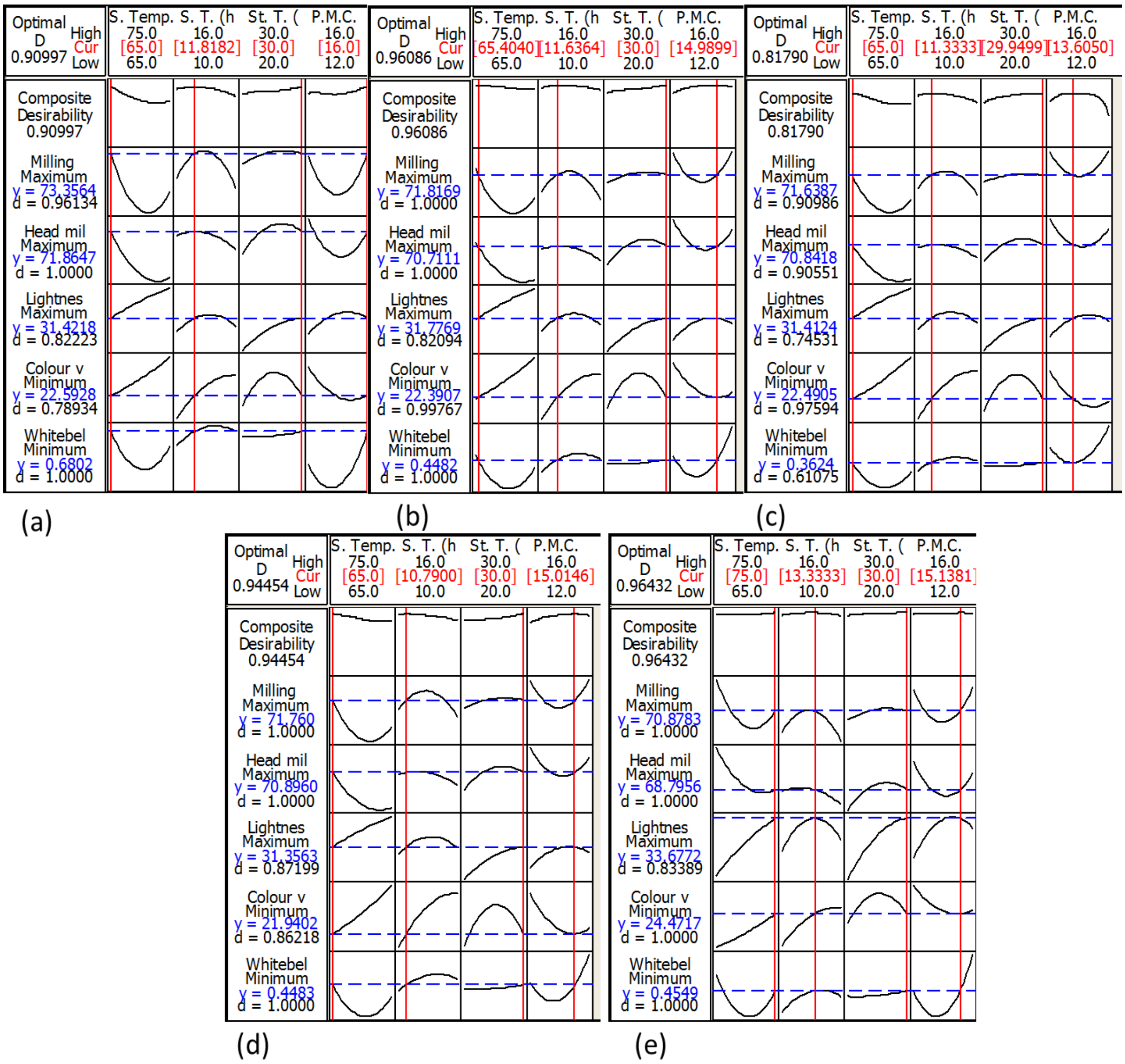

Figure 1: Numerical optimization plot for the optimum processing conditions for (a) FARO 44, (b) FARO 52, (c) FARO 60, (d) FARO 61 and (e) NERICA 8 quality indices (Milling recovery, head milled rice, lightness value, colour value and white bellies). S.Temp is the soaking temperature, S.T is the soaking time, St.T is the steaming time and P.M.C is the paddy moisture content.

4.0 Conclusions

The impact of processing factors; soaking time, soaking temperature, steaming time and paddy moisture content on the quality indices (milling recovery, head milled rice, white bellies, lightness and colour) of five rice varieties were successfully examined using the S/N ratio of Taguchi technique. The impact of processing factors on the quality indices varied significantly on the rice varieties. The predicted optimum processing conditions for FARO 44 was 65°C soaking temperature, 12 h, soaking time, 30 min steaming time and 16% paddy moisture content, FARO 52 (65°C soaking temperature, 12 h, soaking time, 30 min steaming time and 15% paddy moisture content), FARO 60 (65°C soaking temperature, 11 h, soaking time, 30 min steaming time and 14% paddy moisture content), FARO 61 (65°C soaking temperature, 11 h, soaking time, 30 min steaming time and 15% paddy moisture content) and NERICA 8 (75°C soaking temperature, 13 h, soaking time, 30 min steaming time and 15% paddy moisture content). Taguchi technique has proved to be effective in understanding the impact of processing factors on quality indices. Therefore, with minimum experimental runs, adequate information on the impact of processing factors on rice quality can be achieved with the use of Taguchi technique. This study has established that optimum processing conditions varies from one variety to another. Therefore, rice processors are advised not to mix different rice varieties together during processing as this might hinder product quality.

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