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Research Article
Effect of Processing Parameters on the Milling Quality of Brown Rice Using Taguchi Approach

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Abstract
Background and Objective: Brown rice is attaining an increase in demand due to its nutritional and health benefits, therefore, improving its milling quality during processing are of utmost importance. This study evaluate the effect of processing parameters on the milling quality (total brown rice recovery and whole grain brown rice yield) of brown rice obtained from two high yielding improved Nigerian rice varieties (FARO 44 and NERICA 8). **Materials and Methods:** The effect of processing parameters; soaking temperature (65-75°C), soaking duration (10-16 h), steaming duration (20-30 min) and paddy moisture content (12-16%) on total brown rice recovery and whole grain brown rice yield were studied using Taguchi orthogonal array approach. Different treatment combinations were obtained by L_9 (3^4) of Taguchi orthogonal array. **Results:** The larger is better signal to noise ratio of Taguchi gave the optimum processing condition combination. The optimum processing conditions for total brown rice recovery and whole grain brown rice yield, varied significantly based on the rice variety. Paddy moisture content and soaking temperature had considerable influence on total brown rice recovery of FARO 44 and NERICA 8 while soaking duration and steaming duration were found to have more influence on whole grain brown rice yield of FARO 44 and NERICA 8. **Conclusion:** Optimum processing conditions increases total brown rice recovery and whole grain brown rice yield.

Key words: Brown rice, optimization, processing parameters, Taguchi, recovery yield, milling quality

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most commonly consumed cereal food in the world as approximately half of the world's population consume it as staple food. Rice grain is an excellent source of food energy with starch as its main principal component[1]. Unlike other cereal grains, rice is processed and marketed as milled whole grain after polishing. However, due to growing awareness on the nutritional benefit of non-polished type (brown rice), significant number of consumers especially the high income class and nutrition conscious individuals had shifted their rice preference towards consumption of brown rice. Brown rice is made up of endosperm, embryo and outer layer known as bran. According to Mir *et al.*[2] and Meera *et al.*[3], brown rice is beneficial to human health as it is a rich source of polyphenol, antioxidants, minerals, vitamins and fibers.

Total brown rice recovery and whole grain brown rice yield are key quality parameters used in determining efficient milling of brown rice in order to produce and improve its quality. Rice parboiling also known as hydrothermal process involves several unit operations such as, cleaning, soaking, steaming and drying which aid in modifying the qualitative and processing behavior of the milled rice. Taguchi technique is a powerful and efficient tool in Design of Experiment (DoE) technique, which can improve process performance with minimum number of experiments[4,5]. Taguchi technique can be used to find optimal values of the objective function in food manufacturing processes which will reduce manufacturing cost and time. The present study aims to use total brown rice recovery and whole grain brown rice yield as milling quality objective functions for determining the optimum processing conditions for brown rice produced from the two high yielding improved Nigerian rice varieties (FARO 44 and NERICA 8) using Taguchi DoE approach.

MATERIALS AND METHODS

Study area: The study was carried out in grain quality laboratory of National Cereals Research Institute (NCRI), Badeggi, Nigeria from July, 2017-January, 2018.

Selection of varieties: Two high yielding rice varieties, FARO 44 (lowland) and NERICA 8 (upland)) were obtained from the Rice Breeding Laboratory of the National Cereals Research Institute (NCRI), Badeggi, Nigeria. It was manually cleaned and packaged in plastic containers until required for experimentation.

Experimental design: The processing conditions for soaking temperature, soaking duration, steaming duration and paddy moisture content were interacted using Taguchi orthogonal array of design of experiment in Minitab software version 16, U.K. Table 1 shows the outline of interaction of processing parameters using Taguchi experimental design L_9 (3^4). The processing conditions obtained from the interaction were used to evaluate their impacts on total brown rice recovery (%) and whole grain brown rice yield (%).

Laboratory rice parboiling operation: A 14 L digital water bath (Model: WB 14D, Australian) was used to soak the paddy at different soaking temperature (°C) and duration (min) before steaming using a fabricated laboratory rice parboiler. Parboiled paddy was dried to different paddy moisture contents (wet basis). Table 1 shows the interaction of the processing parameters using Taguchi experimental design.

Rice milling operation: Non-parboiled paddy (1 kg) was dried on a tray in an oven set at 34±2°C until moisture content reaches 12, 14 and 16% (wet basis) and milled using laboratory rubber roll rice dehusker (THU 35B, Stake Engineering Corp. Tokyo, Japan) to obtain non-parboiled

Table 1: Outline of interaction of processing parameters using Taguchi experimental design L_9 (3^4)

Experimental runs	Soaking temperature (°C)	Soaking duration (h)	Steaming duration (min)	Paddy moisture content (%)
1	65	10	20	12
2	65	13	25	14
3	65	16	30	16
4	70	10	25	16
5	70	13	30	12
6	70	16	20	14
7	75	10	30	14
8	75	13	20	16
9	75	16	25	12

brown rice. Similar quantity of parboiled paddy was dehusked using laboratory rubber roll rice dehusker in order to separate husk from paddy to obtain parboiled brown rice. The obtained parboiled brown rice samples were then packed and stored. The total brown rice recovery (%) and whole grain brown rice yield (%) were determined for non-parboiled and parboiled paddy[6] using Eq. 1 and 2:

$$\text{Total brown rice recovery (\%)} = \frac{\text{Weight of brown rice (g)}}{\text{Weight of paddy (g)}} \times 100 \quad (1)$$

$$\text{Whole brown rice yield (\%)} = \frac{\text{Weight of head brown rice (g)}}{\text{Weight of paddy (g)}} \times 100 \quad (2)$$

Optimization of brown rice milling quality: Mean total brown rice recovery and whole grain brown rice yield for each processing conditions were calculated. Similarly, average Signal to Noise Ratio (S/N) was also calculated for each level of all factors. A higher amount of total brown rice recovery and whole grain brown rice yield indicates good milling brown rice quality. Therefore, larger is better formula (Eq. 3) was used[7] for calculating the signal to noise ratio of total brown rice recovery and whole grain brown rice yield:

$$SN_{LB} = -10\log_{10}\left[\frac{\sum(\frac{1}{y^2})}{n}\right] \quad (3)$$

where, LB is larger is better, y is the response (total brown rice recovery and whole grain brown rice yield) and n is the number of treatments (nine). The statistical mean was used to check the effect of process parameters and their levels on milling quality by plotting the graph between the mean values of the process parameters and their levels. The milling quality analysis was replicated. Response and Signal to Noise (S/N) ratios of the treatments were analyzed using the Minitab 16 statistical software package U.K. to obtain the main effects of the process parameters and their levels. Optimized factors and levels were selected based on high S/N for the total brown rice recovery and whole grain brown rice recovery. The experimental data obtained for total brown rice recovery and whole grain brown rice recovery for each rice variety were inputted into SPSS software (Version 20, UK) and were evaluated statistically using Analysis of Variance (ANOVA) at $p \leq 0.05$ significance level. Also Origin Pro 8 UK, was used for graphical illustrations.

RESULTS AND DISCUSSION

Effect of paddy grain moisture contents on milling quality: The economic and market values of brown rice is primarily based on high total brown rice recovery and whole grain brown rice yield. Total brown rice recovery and whole grain brown rice yield are among the milling quality indices used in commercial production of brown rice. Brown rice recovery of non-parboiled brown rice was observed to varied significantly ($p<0.05$) based on variety type and paddy grain moisture content. Figure 1 shows the effect of paddy grain moisture content on total brown rice recovery. The FARO 44 had the highest total brown rice recovery when compared with NERICA 8 regardless of moisture content level. This may be related to the differences in the inherent physical properties and behavior of the rice varieties under dehusking conditions. Nasirahmadi *et al.*[8] and Sanusi *et al.*[9] reported differences in the rice recovery of some rice varieties. Highest total brown rice recovery (77.49%) was observed at 14% moisture content in FARO 44 while 73.27% was the highest in NERICA 8 at 12% moisture content.

Figure 2 shows the effect of paddy moisture content on whole grain brown rice yield. The FARO 44 was also observed to have the highest whole grain brown rice yield across the moisture content level as compared with NERICA 8. The highest whole grain brown rice yield (63.44%) was observed at 16% moisture content in FARO 44. The highest whole grain brown rice yield was 61.67% at 12% moisture content for NERICA 8. Alhendi *et al.*[10] reported that moisture content had influence on extraction rate of Yasemin and Anber rice varieties. Also, according to Sanusi *et al.*[9], the minimum achievable whole rice of a quality milling process should not be less than 65% in commercial milling.

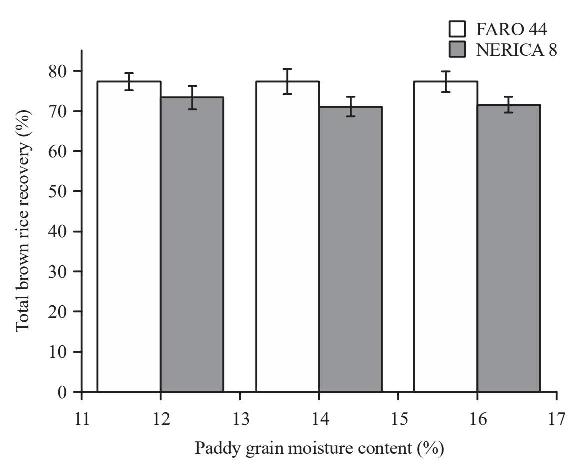

Fig. 1: Effect of paddy grain moisture content on total brown rice recovery

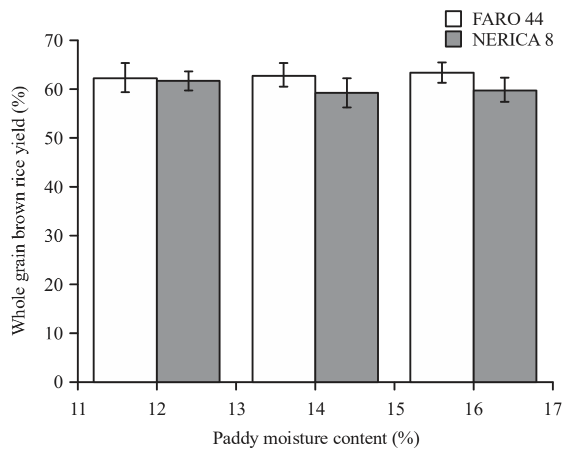

Fig. 2: Effect of paddy moisture content on whole grain brown rice yield

Effect of processing parameters on total brown rice recovery: Figure 3 shows the effect of processing parameters on total brown rice recovery of FARO 44. Paddy moisture content was observed to influence total brown rice recovery of FARO 44 the most under different processing conditions. Soaking duration, steaming duration and soaking temperature were ranked next to paddy moisture content. The larger is better of Signal to Noise ratio (S/N) showed that processing combination of 16 h soaking duration, 65°C soaking temperature, 30 min of steaming duration and 16% paddy moisture content gave the optimum brown rice recovery of 79.41%. This value obtained in FARO 44 is 2.42% greater than non-parboiled total brown rice recovery. NERICA 8 had the optimum total brown rice recovery of 82.40% at processing conditions of 13 h soaking duration, 70°C soaking temperature, 30 min steaming duration and 12% paddy moisture content as shown in Fig. 4. The optimum processing conditions increases total brown rice recovery by 11.1% in NERICA 8 when compared with non-parboiled brown rice recovery. The high values of total brown rice recovery obtained during the processing can be attributed to the starch gelatinization which improves starch structures, by making it to withstand high dehusking pressure that causes milling loss. Nasirahmadi *et al.*[8], Sareepuang *et al.*[11] and Danbaba *et al.*[12] observed that parboiling of paddy aid in improving the quality of polished parboiled rice.

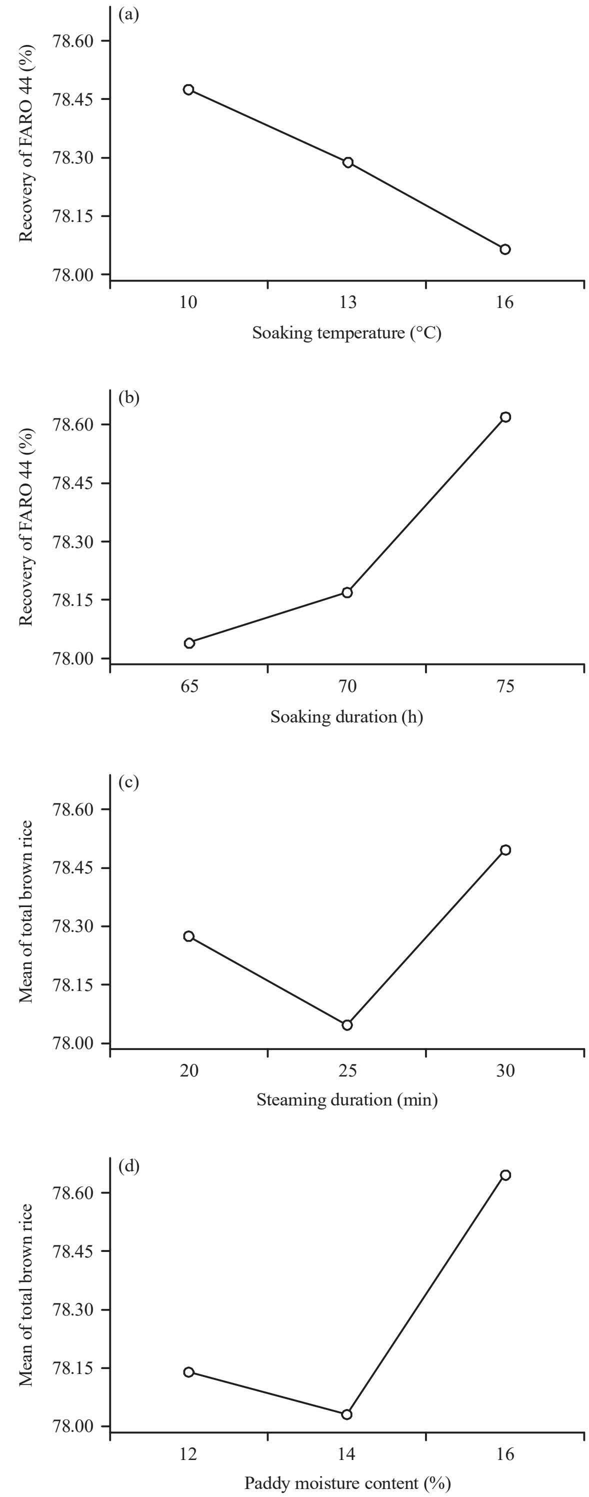

Fig. 3(a-d): Effect of processing parameters on total brown rice recovery of FARO 44, (a) Soaking temperature (°C), (b) Soaking duration (h), (c) Steaming duration (min) and (d) Paddy moisture content (%)

Effect of processing parameters on whole brown rice yield: Figure 5 shows the effect of processing parameters on whole brown rice yield of FARO 44. Soaking duration was observed to have the more influence on whole brown rice yield of FARO 44. Paddy moisture content, soaking temperature and

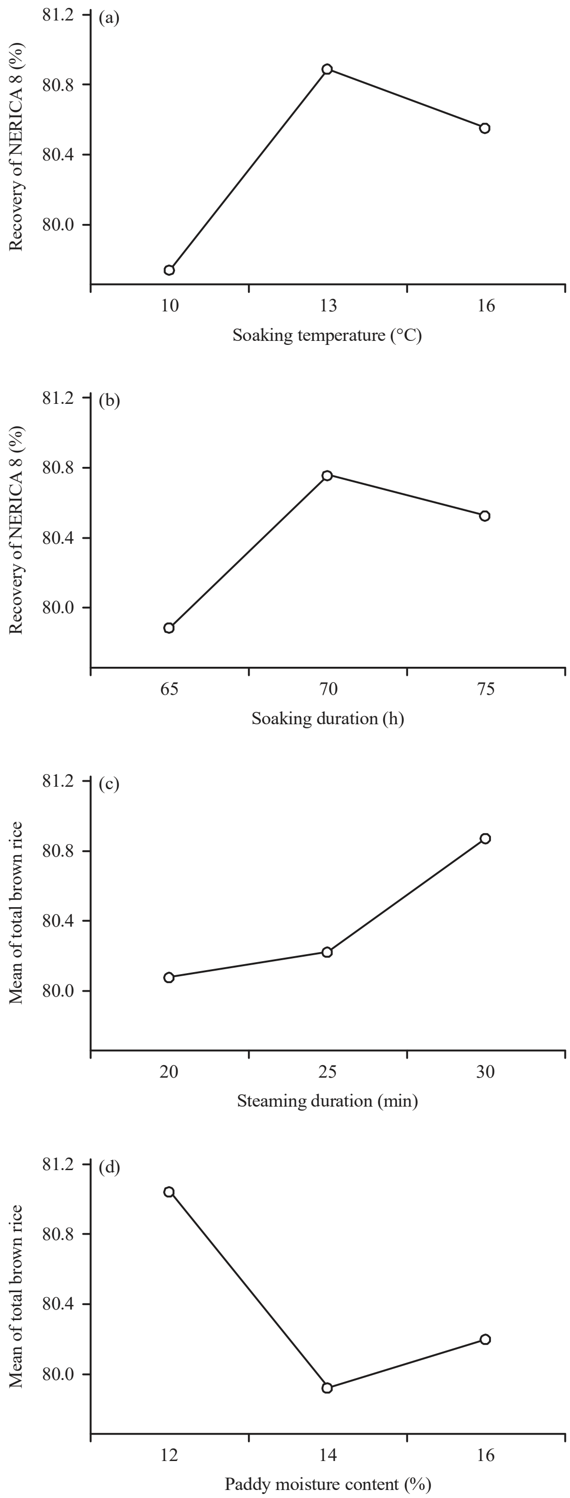

Fig. 4(a-d): Effect of processing parameters on total brown rice recovery of NERICA 8, (a) Soaking temperature (°C), (b) Soaking duration (h), (c) Steaming duration (min) and (d) Paddy moisture content (%)

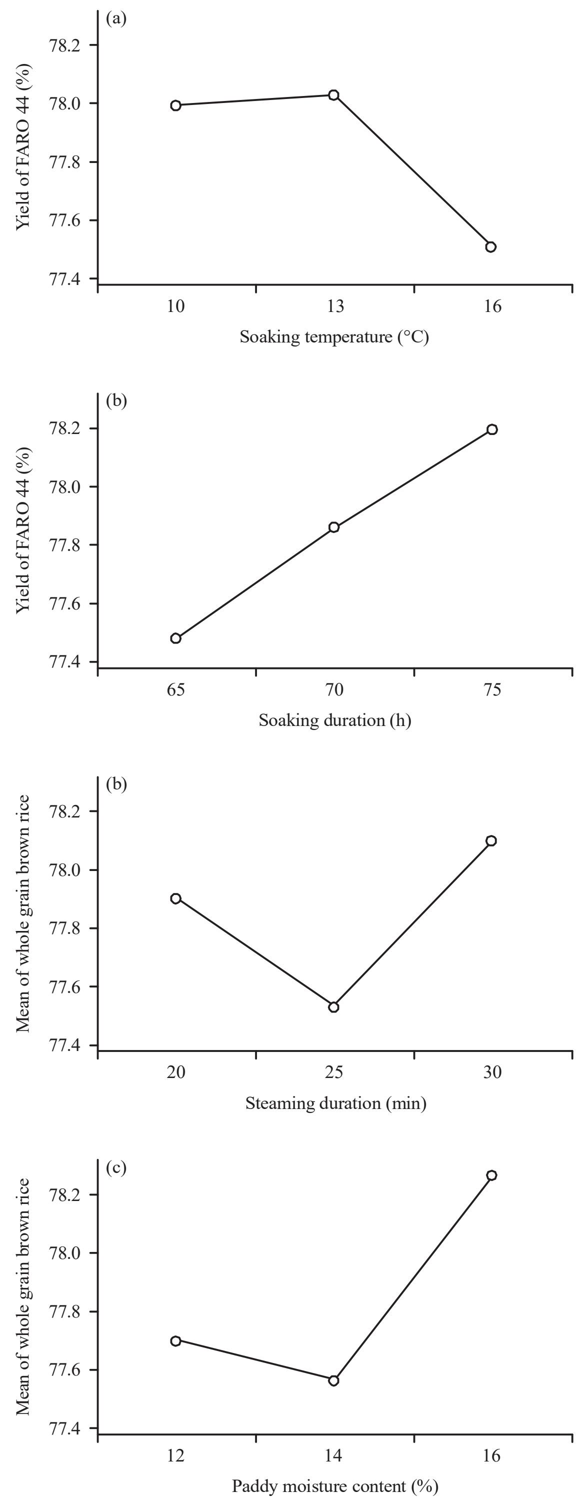

Fig. 5(a-d): Effect of processing parameters on whole grain brown rice yield of FARO 44, (a) Soaking temperature (°C), (b) Soaking duration (h), (c) Steaming duration (min) and (d) Paddy moisture content (%)

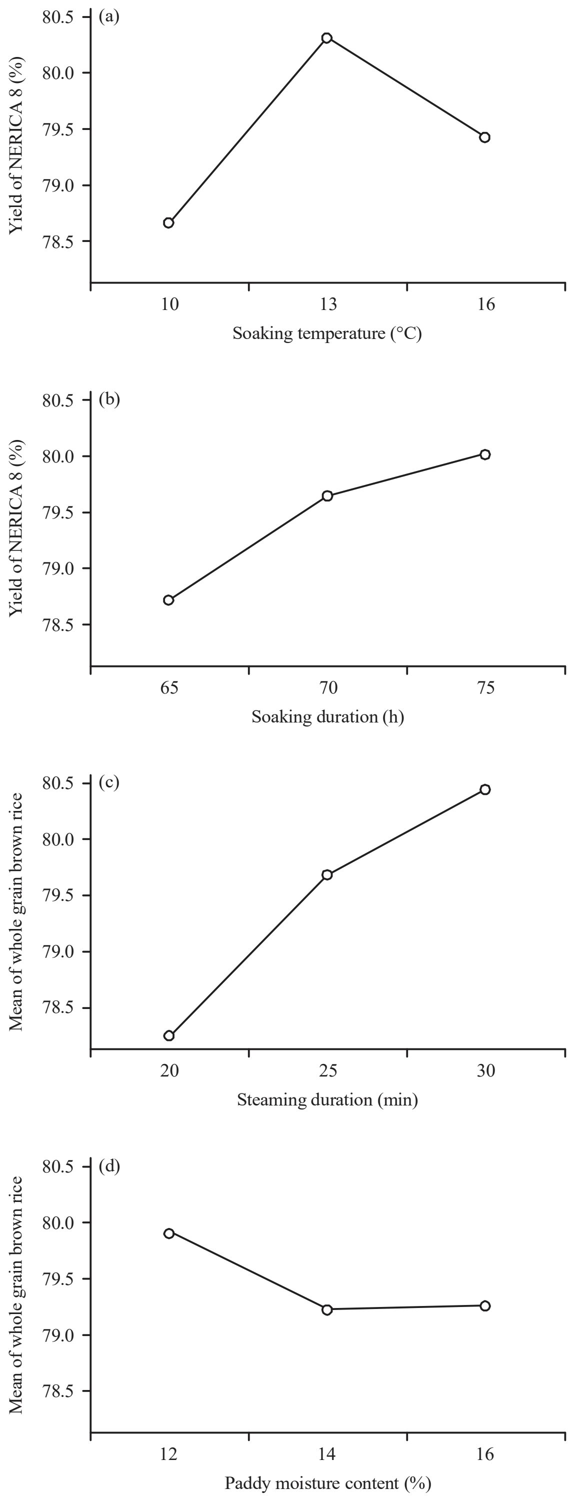

Fig. 6(a-d): Effect of processing parameters on whole grain brown rice yield of NERICA 8, (a) Soaking temperature (°C), (b) Soaking duration (h), (c) Steaming duration (min) and (d) Paddy moisture content (%)

steaming duration were ranked next to soaking duration. The larger is better of Signal to Noise ratio (S/N) showed that processing condition combination of 16 h soaking duration, 65°C soaking temperature, 30 min of steaming duration and 16% paddy moisture content gave the optimum whole grain brown rice yield of 79.02%. This value obtained in FARO 44 was19.71% greater than non-parboiled whole brown rice yields. The NERICA 8 had optimum whole brown rice yield of 81.94% at processing conditions of 13 h soaking duration, 70°C soaking temperature, 30 min steaming duration and 12% moisture content as shown in Fig. 6.

Steaming duration was observed to be the most significant processing parameter on whole brown rice yield of NERICA 8. Parboiled NERICA 8 increased whole brown rice yield by 24.74% as against non-parboiled. Leethanapanich *et al.*[13] and Kwofie *et al.*[14] also observed variation in the yield of parboiled milled rice. In general, total brown rice recovery and whole brown rice yield obtained in NERICA 8 under processing conditions were higher than that of FARO 44. This can be attributed to the fact that rice varieties have different morphological and physical properties thus tend to have different yield under the same condition. Sanusi *et al.*[9] observed the existence of differences in physical properties of four rice varieties.

Paddy grain variety and moisture content have influence on brown rice recovery and whole grain brown rice yield, most especially, when the brown rice is in a non-parboiled state. Therefore, paddy grain must be conditioned to accurate moisture content before dehusking. If paddy grain is not conditioned to desirable moisture content for the processed paddy grain variety, brown rice recovery and whole grain brown rice yield will be low, thus reducing the market value of the brown rice. The right combination of soaking temperature, soaking duration, steaming time and paddy moisture content is needed to produce brown rice recovery and whole grain brown rice yield for optimum values. The larger is better signal to noise ratio of Taguchi approach can be used to establish optimum processing conditions combination.

CONCLUSION

Taguchi orthogonal array approach can be used to optimize brown rice milling quality in terms of total brown rice recovery and whole brown rice yield of two high yielding rice varieties of FARO 44 and NERICA 8 under different processing conditions. Total brown rice recovery and whole grain brown rice yield obtained under non-parboiled conditions were lower considerably when compared with those parboiled. The larger is better signal to noise ratio of Taguchi indicated that paddy moisture content and soaking duration had strong influence on total brown rice recovery and whole grain brown rice of FARO 44 while soaking temperature and steaming duration were found to influence NERICA 8 total brown rice recovery and whole grain brown rice yield the most. Optimum processing condition for each variety differs and Taguchi approach was able to identify the best optimal processing conditions for each.

SIGNIFICANCE STATEMENT

This study shows how Taguchi approach can be used to establish optimum processing condition that can guarantee high values of brown rice milling quality in terms of total brown rice recovery and whole grain brown rice. This will enable the production of acceptable brown rice with high market value. In addition, minimum numbers of experiment is needed to be carried out in Taguchi experimental design before achieving the optimum condition. Thus, aid in reducing experimental cost and time.

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