Optimization and modelling of steam parboiling for improving milled rice grain quality

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Abstract: FARO-44 rice varieties ispoplaramong Nigerian rice farmersbut incidentally has very little postharvest processing information needed to optimally improve the quality of the milled product. This study was, therefore, carried out to determine the optimal conditions for steam parboiling process for increased head rice yield (HRY) andreduced breakage ratio (BR)and also to determine a simulation model for predicting these two quality attributes ofthe milledFARO-44 rice variety.The process variables studied weresoaking temperature (SkT), soaking time (Skt) and steaming time (STt). The SkT was varied between 70°C and 90°C, Sktbetween40 and 50minswhile STtwas varied between 8 to 12hrs.HRYand BR were selected as the quality attributs considered in the optimization as the response variables.The objective of the optimization was to determine the combination of factors that will maximize HRY and minimize BR. At the composite desirability of 0.683, the optimalvalues of SkT, STt and Sktwere76.99°C,40.16minutess and 9.14hours respectively. Under this factor combination,the corresponding values of HRY and BR were88.58%, and 11.26%respectively.These research results are recommended foruse by rice processors to improve the quality attributes of milled rice quality.

Keywords: FARO-44, rice, head rice , breakage ratio, parboiling, modelling

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1 Introduction

Rice has assumedtheposition of an important crop,whichhasoccupieda significant proportion of most governments’strategic efforts in pursuingfood security (EmodiandMadukwe, 2008). It is a staple food for most countries of the world(Chaudhariet al.,2018) and has great potential of becoming their major export commodity. It is eaten as whole-grain and can be converted toflour and subsequently reconstituted in hot water into paste and eaten with soup.Nigeria is the largest producer of Rice (paddy) in Africa with an average production volume of 8 million metric tonnes. As of 2019, Nigeria ranked as the 14th largest producer of rice in the world with China being the top producing country (Enwerem and Ohajianya, 2013;FAO, 1912).As of this 2019, Africa had a total production volume of 14.6Mt, Nigeria produced about 55% and Egypt produced about 30% of the production volume.The current domestic supply does not meet the demand of the country’spopulation of about two hundred million (200 million) people (Ohiaet al., 2020). This resulted in continued rise inexportsofthe commodity over the years and thereby prompting the Federal government to place a ban on importation of rice (Bassey, 2015; DzeverandAyoola, 2017).Desirability for exported rice will largely depend on the quality attributes of its processed form,which in turn depends on the process variables adopted by the processors.Some of the negative attributes of processed rice includes odour, unattractive productsappearance,existence of stones, irregular grains

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sizes, breakages and to some large extent agronomic attributes (Daramola, 2005).All these factors can be addressed throughprocess optimisation to determine the best process input variables for best product quality.

There is no doubt, therefore, that Improved milled rice quality has been the target of rice millers all over the rice producing countries. Quality attributes of milled rice include physical (degree of milling, head rice yield, lightness and color value) and mechanical (rupture force) properties. It is a vital unit opration of rice processing and enhances insect resistance, easy rice milling and better storage properties (Koh and Surh, 2016). Parboiling is pre-milling treatment that involves controlled wet heating by hot water or steam blanching process. Among the unit operations in rice processing, parboiling is adjudged the most critical capable of influencing the final product quality (Himmelsbachet al., 2008). The technical benefits of the process include enhanced nutritional qualities, texture improvement and reduced breakages during milling (Milltec Machinery, 2015). Taghinezhadetal.(2015) studied the effect of soaking temperature and steaming time on the quality of parboiled Iranian paddy rice. In the study, the effect of various parboiling conditions on some quality properties of Fajr paddy was investigated. The author investigated the effect of soaking at temperatures of 55 ℃–75 ℃ and steaming times for 2–10 min. on the physical and mechanical properties of the parboiled rice. Faro-44 paddy is relatively recent in Nigeria and adopted for export and local consumption whereas its milling information has not been fully developed. To address this problem, researches have been ongoing to determine, among others, the optimum parboiling variables (conditions) for improving its milling quality.

Comparatively, parboiled polished (white) rice is 80% nutritionally similar to brown rice because in the process of wet heating vitamins in the bran are leached into the grains (Ayamdooet al.,2013). According to Islam et al. (2001) the process of parboiling makes the paddy rice simpler to handle, increases its dietary value and improves its physical properties.Several studies have been carried out on the impact of hot water parboilingvariablesonmilledrice quality (Danbabaet al., 2014;Yousafet al., 2017; Ogunbiyiet al., 2018; Widyasaputraet al., 2019; Taghinezhadet al., 2019).Most of these studies were done on specific varities of riceusing hot water methods and little of the steam method.

Smallscale rice processors parboiltheir paddy bydirect heating in pot of water (Propcom, 2006; Bello et al.,2015). This methodis characterized by high breakages, low head rice yeid and variegated colouration. Because of the ineffectiveness of pot parboiling method, false bottom method was introduced in an attempt to improve the quality of the milled rice(Ndindenget al.,2015; Agidiet al., 2015). The false bottom parpoiling gadget consists of a pot with false floor made of a perforated metal sheet on which the rice paddy is placed to raise it above the water level in the pot,therebypreventing direct boiling in water.

It is the inefficiency of this process that led to the development of steaming method of parboiling. The steaming equipment consists of boiler, lagged conduit pipes, and the steaming drumwhere the rice paddy is placed above the plenum. The process fluid is the steam generated in the boiler and transported to the steaming drum through the lagged conduit pipes.The objectives of thisworkare to to determine the optimal conditions for steam parboiling process for increased head rice yield (HRY) and reduced breakage ratio (BR) and also to determine a simulation model for predicting these two quality attributes of the milled FARO-44 rice variety.

2Materials and method

2.1 Materials preparation

Raw paddy of FARO-44 rice variety used for this study was obtained from Anambra StateMinistry of Agriculture’s farms Awka,Nigeria. It was cleaned of foreign materials andwashed in clean water before use as experimental samples. The cleaned paddy was divided into 20 sample batches of 25kg each. The parboiling experiment was carried out using the steam parboiler developed by the authors as shown in Figures 1 and 2.

General Legend

Part Number	Description
1	Chimney
2	Steam valve
3	Galvanized steel base
4	Steaming tank Cover
5	Steaming Tank
6	Steam duct
7	Tap/valve
8	Steaming tank stand
9	Water boiling tank

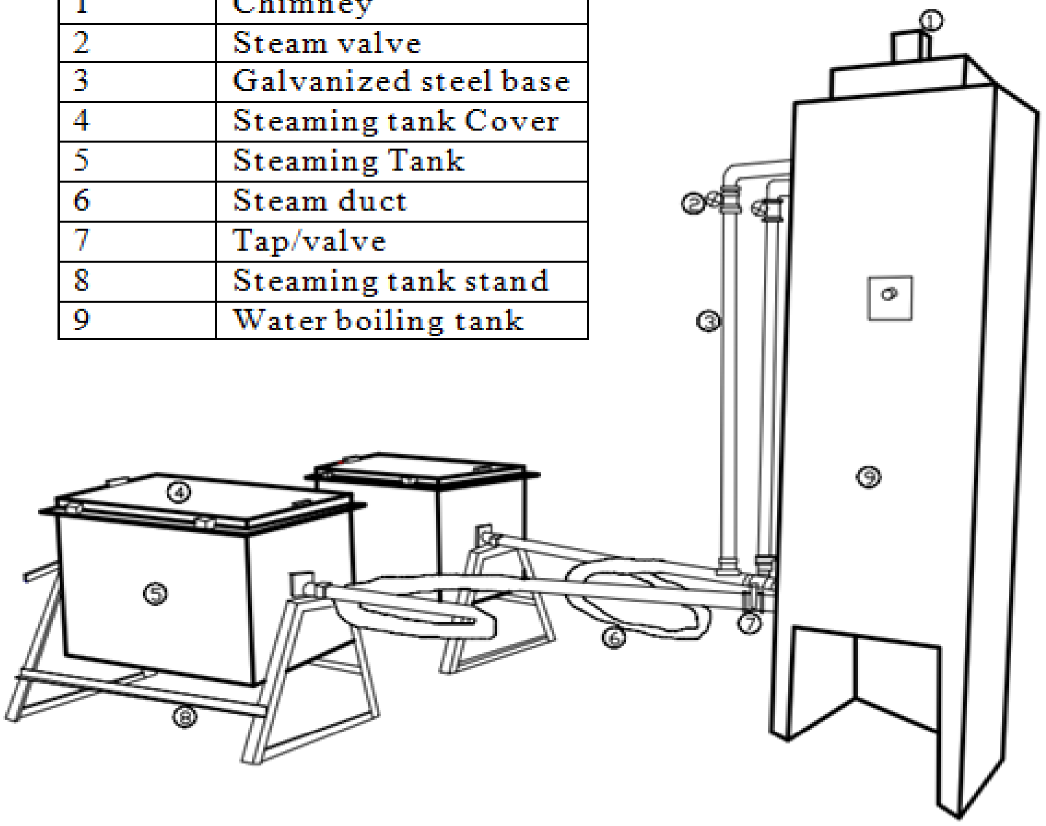


Figure 1 Experimental parboiling equipment

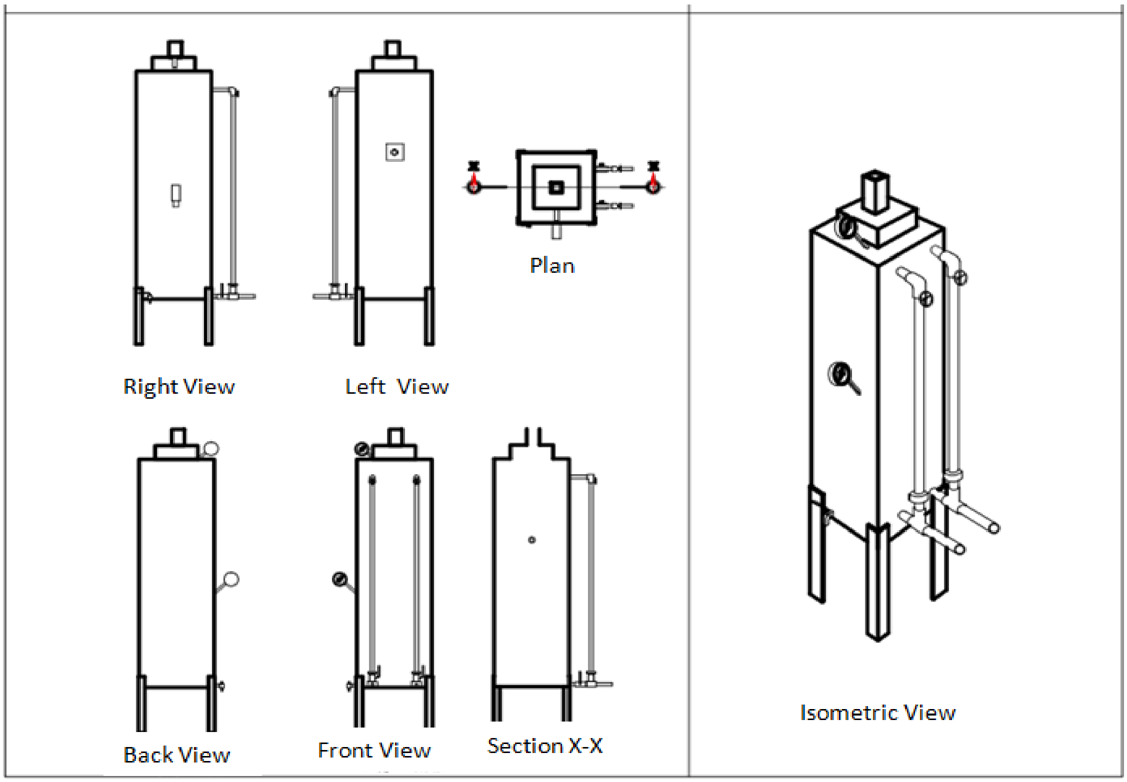


Figure 2 Detailed view of the steaming thank

2.2 Experimental design

The total number of experimental runs N, in Central Composite Design (CCD) is given by Equation1(Myers et al., 2009; Montgomery, 2013;Ahn, 2015; Khuri and Mukhopadhyay, 2010).

$$N = 2^n + 2n + n_c \qquad (1)$$

where$n$ is the number of independent factors and n_c is the number of center points or null points chosen. The term 2^nrepresents the core (factorial) points, $2n$represents the star-like or axial points while$n_c$represents the center points. Six (6) centerpointswere used in the experimental design, which gave a total of twenty (20) experimental runs. These consist of 8 core points, 6 star-like points and 6 center points. The distance of the star-like point α was 1.316. The center points aids in minimizing experimental error while allowing the reproducibility of the data (Myers et al., 2009; Khuri and Mukhopadhyay, 2010; Khodadoust et al., 2014). The star-like points or axial points were used for the rotatability of the experimental runs which makes the variance of the model prediction equidistant from the design center (Ahn, 2015;Sahu et al., 2010).

Theregressionmodelexpressed in Equation 2was used to study the relationship between the response variable and the input variables(Weinberg and Abramowitz, 2008; Frost, 2013).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_2 + \beta_{23} X_2 X_3 + \varepsilon \qquad (2)$$

Where,β_0 is the offset term or model constant,β_1, β_2, β_3 are the linear or first order terms coefficients; β_{11},β_{22},β_{33} are the pure quadratic or squared terms' coefficients, β_{12},β_{13},β_{23} are the interactive terms' coefficients of the quadratic function, $X_1$is steaming time(STt)in seconds, X_2 is the soaking time (Skt) in seconds,$X_3$is the soaking temperature (SkT) in ^{o}Candε is the random error term that allows uncertainties between the experimental and predicted values.Y is the response variable which can either be (%)HRY or (%)BR.

Acceptabilityof the model was based on the p-value expessed in the analysis of variance and the value of the correlation coefficient (R^2). The deviation of the predicted values from the experimental was used measures the accuracy of the regression model. 3D surface plots also helpedtoexplain two-factor interactive effects of the input variables.

Thesoaking temperature (SkT) was varied from 70^{0}C to90^{0}C while thesoakingtime (Skt) was varied from 8hrs to 12 hrs and steaming time (STt) from40minsto 50 mins. According to Sivakamasundari et al. (2020), gelatinization enthalpy decreases as the soaking temperature increasesfrom 30 ℃ up to 90 ℃, and gelatinization enthalpy decreased as steaming times increased from 4 min and 8 min to 12 min.These combinations generated twenty (20) experimental runscomprisingeight (8) factorial point, six (6) axial point and six (6) centre points in the design matrix. These experiments were performed in random maner to avoid systematic error (Muriithiet al., 2017).The experimental data were analysed with Design expert version 11softwae (2011, Stat-Ease Co., USA).

The goodness of fit of the model was estimated by the coefficient of determination(R^2), calculated using Equation 3 (Brereton, 2003; Danbaba et al., 2014;Arulkumar et al., 2011).

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(Y_{i,pre} - Y_{i,exp}\right)^2}{\sum_{i=1}^{n}\left(Y_{i,exp} - Y_m\right)^2} \qquad (3)$$

Where $Y_{i,pre}$ is predicted value of the response variable, $Y_{i,exp}$ is the expected (experimental) value of the same variable, n is the number of experiments and Y_m is the mean value of the variable.

2.3Experimental procedure

The experimental equipment for ths investigation was steam parboiling unit. A 25kg of paddy rice sample was put into eachof the steaming drums.The parboiling process was carried out onthe prepared paddy samples with the factors set at each each experimental condition (Gbaboet al., 2014).*Prior to*each steaming experiment, the paddy samples were soaked in hot water at temperaturesvaried from70^{o}Cto 90^{o}C (SkT) for periods of time that variedbetween 40 to 50mins (Skt).When steaming was competed, the paddywas dried to an average moisture content of about 12.5 %(wb).A milling machine (Model S1115NMB) of 22 horsepower with a speed of 2200rpm (≈ 35ms^2) was used to milleach of thedriedparboiled paddy samples. Weight of each sample was taken before and after milling. The rice was subsequently graded by a gradingmachine(Model MMJP63×3) to obtain the recovered head rice and broken rice respectively.

2.4The quality attributes of milled rice.

The quality parameters considered in this study were HRY (%) and BR (%).

2.4.1 Head rice yield

The grading machine used has the capability ofseparating whole grains from broken grains. The HRY was calculated as a percentage of whole milled grains (WMG)in terms oftheweight of dried parboiled paddy as shown in Equation4(Gbabo et al., 2014).

$$HRY\ (\%) = \frac{Weight\ of\ WMG\ (g)}{Total\ weight\ of\ dried\ parboiled\ paddy\ (g)} \times 100 \quad (4)$$

2.4.2 Percentage breakage ratio

The percentage of the broken grains was computed using Equation5. The broken kernels comprise all grains that were not whole in length or less than ¾ of the expected whole length(Gbabo et al., 2014).

$$BR\ (\%) = \frac{Weight\ of\ broken\ grains(g)}{Total\ Weight\ of\ dried\ parboiled\ paddy\ samples(g)} \times \frac{100}{1} \quad (5)$$

3 Results and discussion

3.1 Head rice yield (HRY)

A quadratic model was developed to preict HRY as a function of SkT, Skt, and STt as shown in Equation 6.From the equation, it can be deduced that increases in SkT, SktandSTt lead to increase in HRY.

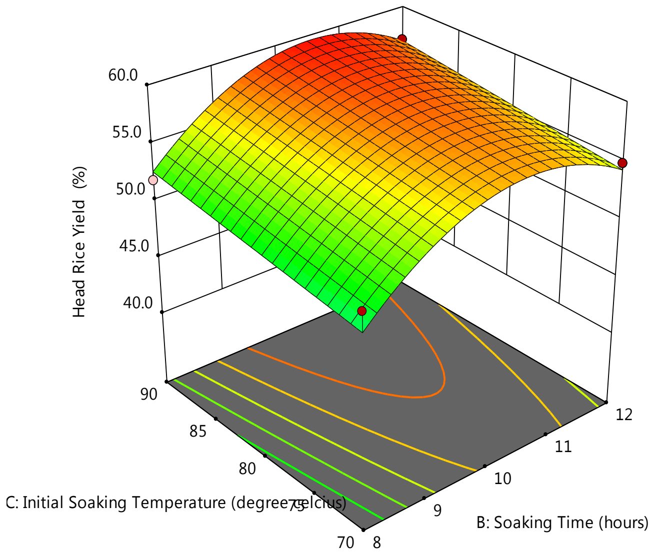
$$HRY = -320.68 + 8.39 * STt + 18.87 * SKt + 3.01 * SKT - 0.05 * STt * SKt - 0.02 * STt * SKT - 0.09 * STt^2 - 0.95 * SKt^2 - 0.01 * SKT^2 \quad (6)$$

The predictedvaluesof HRY varied from 77% and79.3% with a mean of 78.15%. This findingdidnot differ much from the findings of other investigators who reported as follows: 62.13% to 68.13% (Taghinezhadet al.,2019), 65.9% to 70.9% (Ogunbiyiet al., 2018), 60.8% to 73.88% (Yousafet al.,2017) and 30.11% to 75.76% (Danbabaet al.,2014).The observed deviations may be due to variations in rice varieties, methodsor experimental error.

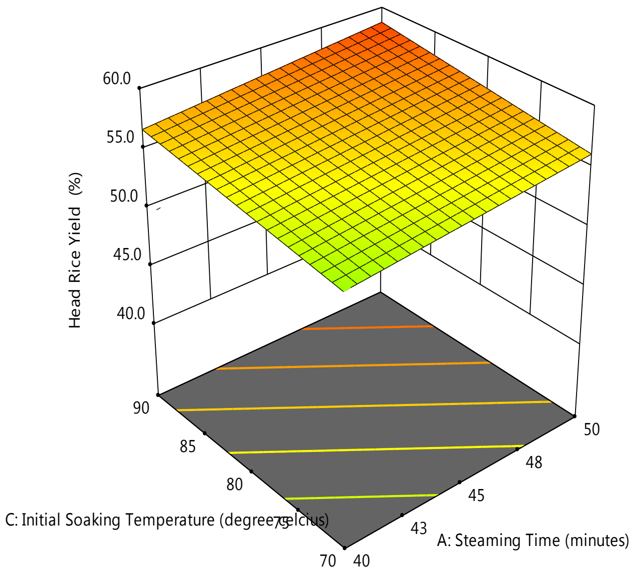
The goodness of fit of the model was further confirmed by the value of coefficient of correlation (R^2)of0.8244at 95% CI. This implies thatwe are 95% confident that the mean %HRYof*faro-44* rice variety is 78.15% at the optimized process condition. The standard error of the mean is 0.3 which is considered good enough. The analysis of variance (ANOVA) for the quadratic model is presented in Table 1.

Table 1 ANOVA table for head rice yield

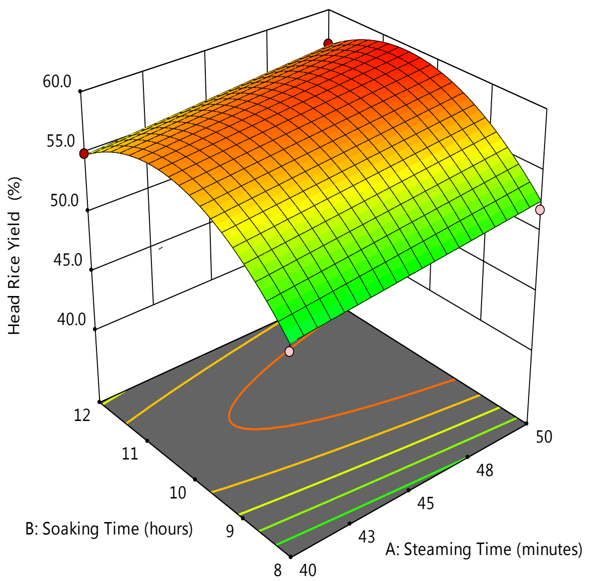
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	302.43	4	75.61	72.97	< 0.0001	Significant
A-Steaming Time	13.33	1	13.33	12.87	0.0027	
B-Soaking Time	56.30	1	56.30	54.33	< 0.0001	
C-Initial Soaking Temperature	22.89	1	22.89	22.09	0.0003	
B^2	209.91	1	209.91	202.58	< 0.0001	
Residual	15.54	15	1.04			
Lack of Fit	11.19	10	1.12	1.29	0.4125	not significant
Pure Error	4.35	5	0.8704			
Cor Total	317.97	19				



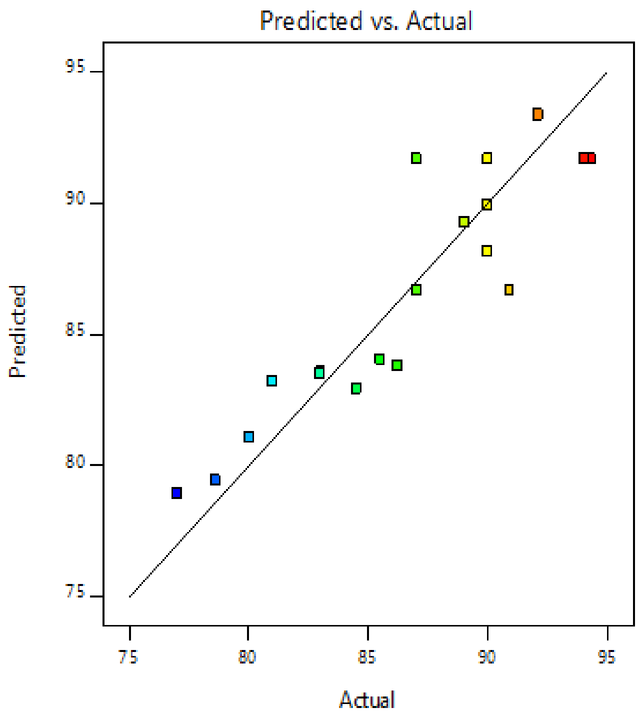
(a) Soaking temperature and soaking time against HRY



(b) soaking temperature and steaming time against HRY



(c) soaking time and steaming time against HRY



(d) Predicted vs actual values of HRY

Figure33-D plots interactive plots

The Model F-value of 5.21 implies the model is significant. There is only a 0.82% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this caseSoaking temperature (C), second order of Steaming time (A^2) and second order of Soaking time (B^2) are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. The Lack of Fit F-value of 0.81 implies the Lack of Fit is not significant relative to the pure error. There is a 61.10% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good since the model is expected to fit.

Surface response interaction graphs of the steam parboiling variables againstHRYare shown in Figures 3 (a –c) while Figure3(d) represented the calibration graph of predicted response variables against observed values. From the graphs, HRY increases with increasing soaking temperature and soaking time.

3.2Breakage ratio (BR)

Curvefitting was used to develop a predictive Quadratic model for BR as a factor of the SkT, Skt and STt. The quadratic model based on the actual factors is given in Equation 8.

The terms in STt, STt^2, and Skt^2 all have a positive effect on BR. This shows that an increase in these terms will lead to an increase in BR. The observed value of BR rangesbetween 5.7%and23%. This findingdiffers from the report of Ogunbiyietal.(2018)that ranges between 1.80% and 3.40%. The observed difference may be due to variation in sample rice variety as he used FARO-52.

The coefficient of determination (R^2), adjusted R^2 and predicted $R^2$are 0.8229, 0.7711 and 0.6627 respectively at 95% CI.

$$BR = 417.59 - 8.30 * STt - 18.48 * Skt - 3.04 * SkT - 0.06 * STt * Skt + 0.018 * STt * SkT + 0.02 * Skt * SkT + 0.09 * STt^2 + 0.95 * Skt^2 + 0.01 * SKT^2 \quad (7)$$

Table 2shows the analysis of variance (ANOVA)result for the quadratic the model. The Model F-value of 5.42 implies that the model is significant. There is only a 0.72% chance that an F-value this large could occur due to noise (error).

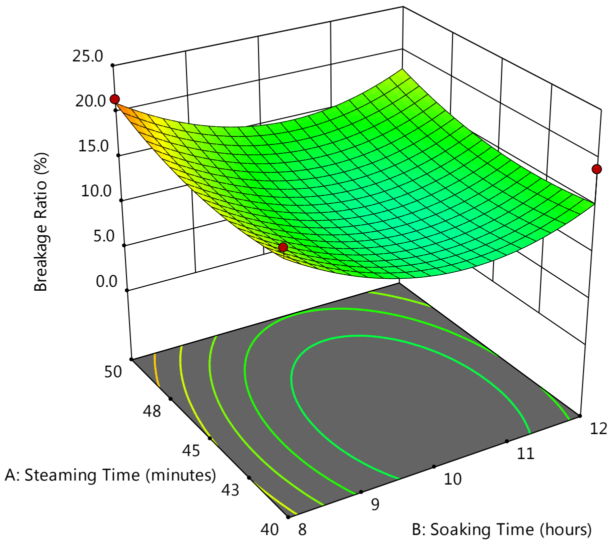
P-values less than 0.0500 indicate model terms are significant. In this case C, A^2, $B^2$are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The Lack of Fit F-value of 0.78 implies the Lack of Fit is not significant relative to the pure error. There is a 62.41% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good since the model is expected to fit.

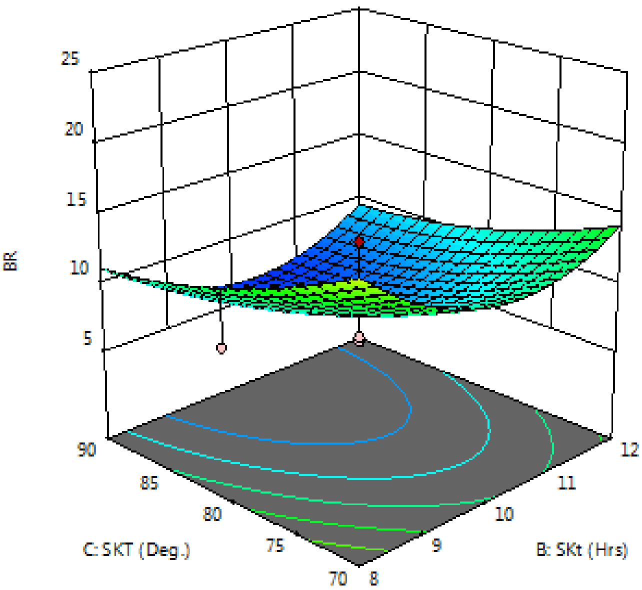
Table 2 ANOVA table for rice breakage ratio

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	392.19	5	78.44	13.80	< 0.0001	Significant
A-Steaming Time	21.53	1	21.53	3.79	0.0720	
B-Soaking Time	30.42	1	30.42	5.35	0.0364	
C-Initial Soaking Temperature	102.96	1	102.96	18.12	0.0008	
A^2	35.11	1	35.11	6.18	0.0262	
B^2	205.10	1	205.10	36.09	< 0.0001	
Residual	79.55	14	5.68			
Lack of Fit	42.53	9	4.73	0.6382	0.7372	not significant
Pure Error	37.02	5	7.40			
Cor Total	471.74	19				

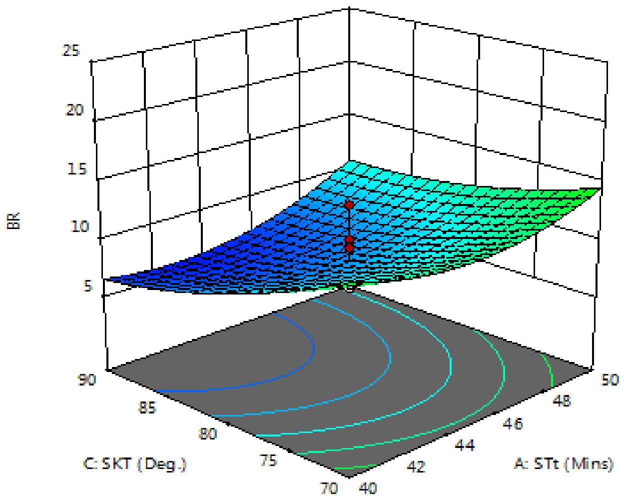
Surface response plots of parboiling variables against BR are shown in Figures 4 (a-c) and Figure 4(d) represents the calibration curve of predicted BR against the observed values. The 3-D plots help to explainthetwo-way interactions between any two independent variablesand their effects on Breakage Ratio.The trend shows that BR decreases as steaming time increasesup to 44mins but afterwards increases as steaming time continues to increase. On the other hand, BR decreases as the soaking time increases up to 10hrs but increases as soaking time increases beyond 10hrs. Further investigation showed that BR decreases as Soaking Temperature increases.



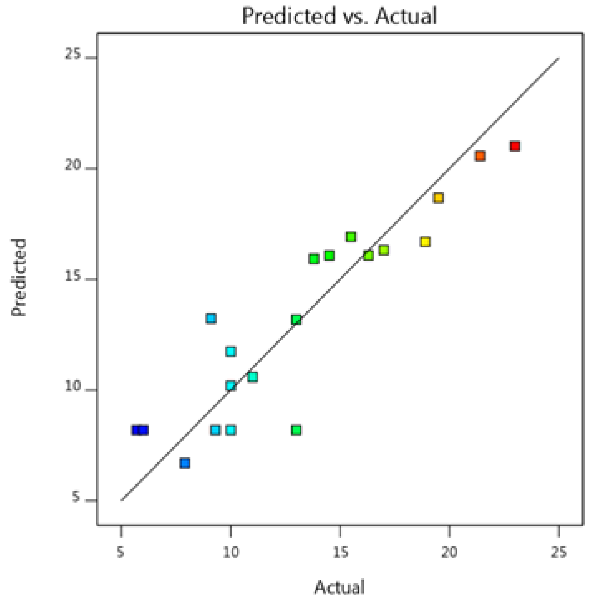
(a) Steaming time and soaking time against BR



(b)Soaking temperature and steaming time against BR



(c) Steaming temperature and soaking time against BR



(d) Calibration graph of actual vs predicted values of BR

Figure4 3-D plot interactive plots

3.3Numerical optimizations

The objective of this workis to obtain the optimal parboiling condition in terms of SkT, SKtandSTt in relation to HRYandBR. The optimization goals are:MaximizeHRYandMinimizeBR. In Design expert v.11 software used, 0 is minimum desirability while 1 is maximum desirability. The optimal parboiling condition was determined based on the maximum desirability of 0.683.Thepredicted optimum condition was 40.16 mins of Steaming time, 9.14 hours of Soaking timeand76.99°C of Soaking Temperaturehaving desirability index of 0.683.The above optimum parboiling condition for FARO-44 rice variety produced percentage head rice yield as high as 78.15%and minimal breakage ratio of 6.7%.Taghinezhadet al. (2015) reported that head rice yield increased significantly (p< 0.05) from 50.10% to 62.11%–67.05% at soaking temperature of 65℃ and 4 min steaming time for Fajr paddy (Iranian paddy).

4 Conclusion

Response surface methodology in CCD was successfully applied to optimise the processvariables in steam parboiling of FARO-44 rice variety. Head rice yield and breakage ratio were selected as the rice qualityattributesforoptimization. Based on the result of analysis, the predicted optimumfactor combination was 40mins of Steaming time, 9.14 hours of Soaking time and 76.99°C of Soaking Temperature. Under this parboiling condition, the predictedheadriceyield was 78.15% based on dried parboiled paddy weight and breakage ratio of 6.7% on composite desirability of 0.683.

Variations in the independent variables (STt, Skt, SkT) significantly influenced the response variables (HRY and BR). Increase in soaking time above the optimum condition led to a gradual decline in Head Rice Yield.

Increase in steaming temperature and steaming time resulted inagradual increase in head rice yield. The soaking temperature and soaking time had more effect on the Breakage Ratio than the steaming time.

Theresultsof this study is recommended for use by rice processorsto improve the physical quality attributes of milled FARO-44 rice variety.

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