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Research article

Interactive effects and modeling of some processing parameters on milling, cooking, and sensory properties for Nigerian rice using a one-step rice milling machine

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ABSTRACTS

This study investigates the interactive effects of processing parameters on the quality of milled rice using a one-step milling machine. Also, predictive models were generated using response surface methodology. The processing parameters were moisture content (10–14 % dry basis), shaft speed of rotation (600–900 rpm), and polishing time (1–3 min). The quality parameters evaluated were milling (head rice yield, percentage broken rice, fine broken rice, and milled rice yield), cooking (optimum cooking time, kernel elongation ratio, and width expansion ratio), and sensory (flavor, aroma, appearance, texture, and overall acceptability) properties. The results showed that the interactive effects of moisture content, shaft speed, and polishing time were significant ($P < 0.05$) on percentage broken rice, milled rice yield, fine broken rice, optimum cooking time, kernel elongation ratio, width expansion ratio, aroma, and appearance but was not significant on head rice yield, flavor, texture, and overall acceptability. These results were similar to the regression models generated. In conclusion, the interactive effects of these processing parameters affect all the cooking properties but not all milling and sensory properties while using a one-step milling machine.

1. Introduction

Rice is a staple food for over half of the world population constituting over 3 billion people (Falade and Christopher 2015; Taghinezhad and Brenner, 2016). Approximately 4 billion people consume rice globally (Ojediran et al., 2018). The consumption of rice globally in 2018 was estimated to be 414 million metric tons, in which Sub-Sahara Africa (SSA) consumed about 26.6 million metric tons (Competitive African Rice Initiative, 2018). In Nigeria, rice stands as the fourth most important crop following sorghum, millet, and maize in terms of its cultivated landmass (Olayanju et al., 2019). It is an important crop because it serves as a good source of carbohydrates with a wide range of nutrients including vitamin B, proteins, lipids, and fiber (Saikrishna et al., 2018; Lee et al., 2018). Due to the usage of rice in the production of bread, alcoholic drinks, and other traditional recipes, its production and consumption have been on an increase (Ojediran et al., 2018). The most common quality parameters are; milling, cooking, sensory, and nutritional (Saha et al., 2007). Rough rice processing involves the following unit operations; cleaning, parboiling, drying, tempering, milling (husking and polishing), grading, and de-stoning (Zabidin et al., 2018). The rough rice consists of the husk (outer protective covering), bran, aleurone layer, embryo, and the starchy endosperm. The milling operation is an intricate part of the processing line which removes the husk and bran layer. Husk and the bran layer constitute about 28 % of the paddy weight. Polished or white rice is obtained when the bran, aleurone layer, and the embryo are removed remaining the starchy endosperm (Bangphan et al., 2013; Liu et al., 2017). Polished rice is more appealing to the consumer, and it is characterized by longer shelf life, better cooking attributes, and faster digestibility although brown rice is more nutritious (Rathna Priya et al., 2019). There are three different rice milling machines; one-step (husking and polishing in a single run), two-step (husking and polishing or whitening are carried out with two different machines), and multi-stage (comprises of the pre-cleaning unit, husking, paddy separation, polishing, grading, a combination of whole and broken rice in percentage, mist polishing, and weighing) rice milling machines (Dhankhar and Hissar 2014; Ojediran et al.' 2020).

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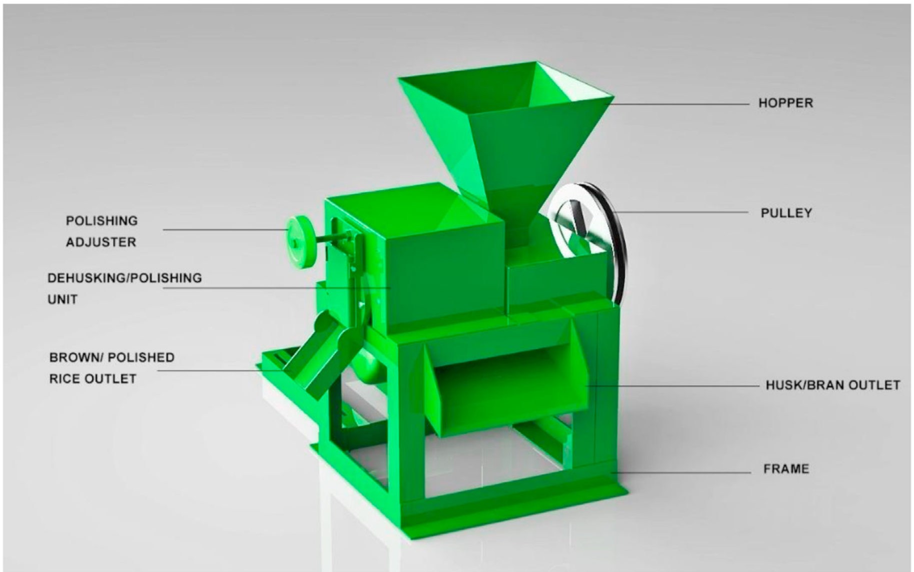

Figure 1. One-step paddy rice milling system.

The quality of the rice milling process can be affected by both material (moisture content, variety, parboiling conditions, shape, and size) and machine parameters (shaft speed, screen clearance, milling shaft configuration, and polishing time). Some researchers have evaluated the effects of some of these processing parameters that influence rice milling. Payman et al. (2007) studied the effect of moisture content and shaft speed on the rice breakage experienced during husking operation using a rubber roll husker. It was reported that the interactive effect of shaft speed and moisture content significantly affected the hulling index but did not affect the amount of rice breakage. Firouzi et al. (2010) studied the effect of shaft speed and paddy moisture content on the performance of rubber roll husker. They revealed that an increase in paddy moisture content decreased the de-husking efficiency and increased the percentage of broken rice while an increase in shaft speed decreased the broken rice percentage and increased the de-husking efficiency at the start but decreased afterward. Nasirahmadi et al. (2014) studied the influence of moisture content, variety, and parboiling on rice milling properties. They reported that a decrease in moisture content increased the head rice yield and milling recovery of the two rice varieties used. Sandhu et al. (2018) studied the effect of the polishing time on the physicochemical, structural, pasting, and cooking properties of short and long-grain Indica rice varieties. It was observed that a high polishing degree increased the elongation ratio, gruel solid loss, length/breadth ratio, and pasting viscosities. Rodríguez-Arzuaga et al. (2015) studied the effect of the polishing time on the sensory qualities (appearance and aroma characteristics) of raw rice. The impact of polishing time was noticed between brown and milled rice samples. Cooked-rice appearance was also found to be most obvious between brown rice and milled-rice samples. Qiu et al. (2019) investigated the combined effect of shaft speed and milling duration on the physicochemical properties (amylose content, swelling power, and water solubility index, pasting properties, thermal properties, and in vitro starch digestibility) of rice. Thermal properties were discovered to be controlled by the milling duration and the shaft speed. Ahmad et al. (2017) evaluated the effect of milling intensity and storage duration on some quality parameters of Catahoula rice like; proximate, surface morphology, color, textural, and milling properties. They found out that an increase in the milling intensity resulted in high water absorption, easier compression, and greater gelatinization of cooked rice kernels.

It was observed from the above literature review that the interactive effects of moisture content, shaft speed of rotation, and polishing time on rice quality like milling, cooking, and sensory have not been exploited. No predictive models are combining these process variables, which are mostly used as a quality determinant in food industries. Predictive models show how the quality parameters relate well with the process variables, which is a highly beneficial tool to processing industries, as an outcome of the adjustment in the processing conditions can be easily predicted before it is adopted. Also, previous research work has only utilized the two-step milling system for their study, using a one-step milling machine will increase the knowledge-base for rice processing industries. However, this present work is an extension of our previous work undertaken to study the effect of polishing time on milling, physical, cooking, and sensory properties of Nigerian rice by Ojediran et al. (2020). Thus, this work aimed to study the interactive effects of moisture content, shaft speed, and polishing time on milling, cooking, and sensory properties for a Nigerian rice cultivar, also to model the processing parameters.

2. Materials and method

2.1. Sample preparation

The long-grain brown rice cultivar (FARO 58) was gotten from the International Institute of Tropical Agriculture (IITA), Ibadan, Oyo State. The initial moisture content on a dry weight basis (MC % db) of the rough rice before soaking, after soaking, and after steaming were determined using the oven-dry method in triplicate (i.e. drying at 110 °C for 24 h) (ASAE, 1988). The moisture content was 14.13 ± 0.3% db before soaking, 59.35 ± 0.21 % after soaking, and 46.09 ± 0.35% after steaming. Before each experiment, the rough rice was cleaned using a laboratory winnower, afterward washed under a running water tap severally to remove the immature grains and other impurities. The washed paddy was soaked in water at 60 °C in a constructed laboratory electric parboiler for 12 h. After the soaking operation, the paddy was evacuated from the drum, and the water drained to one-third of the parboiler volume (Gbabo et al., 2008). When steam started emanating from the parboiler (temperature >80 °C), paddy rice was introduced on an elevated platform and steamed for 40min (Gbabo et al., 2008). A thin layer of the steamed paddy rice was spread on a tray and allowed to equilibrate for 15min under ambient conditions (temperature-27 °C and relative humidity-55 ± 0.35%). Afterward, the paddy was dried in a laboratory oven (Model-Memmert UF 75) at 70 °C to the desired moisture content 10, 12, and 14 % db for the duration of 4, 3, and 2 h. These samples were finally tempered for 15min under ambient conditions

Table 1. Processing variables use for the experimental evaluation and response surface modeling.

	Independent variables	Real/coded value		
1	Moisture content (% dry weight basis)	10 (-1)	12 (0)	14 (+1)
2	Shaft speed of rotation (rpm)	600 (-1)	750 (0)	900 (+1)
3	Polishing time (min)	1 (-1)	2 (0)	3 (+1)

(temperature-27 °C and relative humidity-55 ± 0.35%) to reduce the temperature of the paddy to 30 °C before milling.

2.2. One-step rice milling machine

The one-step milling machine was constructed in the department of Agricultural and Biosystems Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria as shown in Figure 1. It is a horizontal milling system capable of husking and polishing in a single run. The polishing adjuster determines the level of polishing and the polishing time. The polishing adjuster was calibrated from preliminary investigations using a constant weight of parboiled paddy (1 kg) to establish the time of polishing. At complete disengagement of the polishing adjuster, the duration of milling was 30 s. The polishing adjuster causes a delay of the rice grains in the milling unit. The choice of the polishing time used was based on Singh Gujral et al. (2002) who adopted a milling duration of 5–120 s.

2.3. Milling properties

2.3.1. Head rice yield (HRY)

The head rice was referred to as grains with at least three-quarter of the kernel length. The head rice yield was calculated using Eq. (1) (Hapsari et al., 2016; Falade and Christopher 2015).

$$\mathrm{HRY}\ (\%) = \frac{\text{head rice}}{\text{mass of rough rice}} \times 100 \tag{1}$$

2.3.2. Percentage of broken rice (BR)

The broken rice was referred to as grains that are less than three-quarter but greater than one-fourth of the actual kernel length. The percentage of broken rice was calculated with Eq. (2) (Chavan et al., 2017).

$$\mathrm{BR}\ (\%) = \frac{\text{broken rice}}{\text{milled rice}} \times 100 \tag{2}$$

2.3.3. Fine broken rice (FBR)

Fine broken rice was referred to as grains that are less than and equal to one-fourth of the actual kernel length. This was calculated using Eq. (3) (Ahmad et al., 2017; Okunola et al., 2019; Ojediran et al., 2020).

$$\mathrm{FBR}\ (\%) = \frac{\text{fine broken rice}}{\text{milled rice}} \times 100 \tag{3}$$

2.3.4. Milled rice yield (MRY)

The milled rice comprises head rice, broken rice, and fine broken rice. Milled rice yield was evaluated using Eq. (4), as suggested by Chavan et al. (2017).

$$\mathrm{MRY}\ (\%) = \frac{\text{milled rice}}{\text{rough rice}} \times 100 \tag{4}$$

2.4. Cooking properties

The following cooking properties were evaluated as suggested by Chen et al. (2012), Chavan et al. (2017), and Devraj et al. (2019).

Table 2. Milling, cooking, and sensory results at the various processing combinations.

Run	MC (% db)	SR (rpm)	PT (min)	HRY (%)	BR (%)	MRY (%)	FBR (%)	OCT (min)	KER	WER	AR	FL	TX	AP	OA
1	0	0	-1	82.21	7.31	94.04	4.52	13	1.10	1.10	6.50	5.13	5.13	4.88	5.63
2	0	0	0	80.29	9.23	94.42	4.90	21	1.14	1.10	6.50	5.13	6.75	6.50	8.25
3	0	0	1	81.31	6.21	96.26	8.74	12	1.14	1.18	6.38	5.38	6.00	6.38	7.50
4	0	1	0	81.30	10.41	98.33	6.63	19	1.17	1.22	6.38	5.63	4.75	4.13	6.00
5	0	-1	0	78.97	7.94	92.62	5.71	17	1.12	1.16	4.88	5.50	5.63	3.63	5.75
6	0	0	0	79.51	7.17	96.07	9.39	14	1.14	1.24	6.00	4.88	4.75	5.00	6.25
7	-1	0	0	89.15	3.81	94.33	1.36	19	1.14	1.09	5.83	5.83	5.67	5.17	6.33
8	-1	-1	1	90.50	5.21	96.96	1.26	14	1.13	1.12	5.90	6.10	5.80	6.20	6.90
9	-1	-1	-1	88.21	3.96	93.19	1.02	12	1.06	1.07	6.00	5.80	5.00	5.50	6.50
10	1	-1	1	82.05	9.83	97.35	5.47	15	1.14	1.10	6.44	6.33	5.56	6.11	7.67
11	1	1	1	85.25	8.12	98.11	4.75	16	1.11	1.16	6.33	5.50	5.83	6.50	7.33
12	1	0	0	83.87	9.23	96.85	3.74	21	1.12	1.09	6.33	6.33	5.83	6.33	7.83
13	-1	1	1	84.45	8.07	98.91	6.39	15	1.16	1.14	6.10	6.10	6.10	6.20	7.70
14	-1	1	-1	82.65	6.74	95.29	5.91	19	1.13	1.15	7.17	6.00	6.17	5.00	7.67
15	1	1	-1	84.65	7.36	94.80	2.79	16	1.13	1.18	6.14	6.14	5.43	7.14	7.71
16	1	-1	-1	84.31	8.18	95.43	2.95	11	1.18	1.14	5.80	5.80	6.30	6.50	7.20
17	0	0	0	89.75	3.72	94.46	0.99	16	1.18	1.22	6.38	6.13	4.88	6.25	7.13
18	0	0	0	89.54	2.77	93.96	1.66	16	1.13	1.15	6.75	6.50	6.88	7.38	8.50
19	0	0	0	83.14	7.66	94.79	3.99	16	1.14	1.12	6.63	6.13	5.88	6.38	7.38
20	0	0	0	83.73	7.98	96.60	4.88	16	1.14	1.14	5.88	4.75	5.50	5.00	5.88

MC = moisture content (% dry weight basis), SR = shaft speed of rotation, PT = polishing time (min), HRY = head rice yield, BR = broken rice, MRY = milled rice yield, FBR = fine broken rice, OCT = optimum cooking time, KER = kernel elongation ratio, WER = width expansion ratio, AR = aroma, FL = flavor, TX = texture, AP = appearance, OA = overall acceptability.

Table 3. 9-point hedonic scale used for sensory evaluation.

CODE	Interpretation
1	Dislike extremely
2	Dislike very much
3	Dislike moderately
4	Dislike slightly
5	Neither like nor dislike
6	Like slightly
7	Like moderately
8	Like very much
9	Like extremely

2.4.1. Kernel elongation ratio

The kernel elongation ratio (KER) refers to the ratio of the cumulative length of 10 cooked rice kernels to 10 un-cooked rice kernels.

2.4.2. Optimum cooking time

The optimum cooking time (OCT) was evaluated by soaking 2 g of whole grain in distilled water (20 ml) contained in a test tube heating at 90 °C in a water bath. During the OCT determination, few rice kernels were removed from the test tube at different time intervals and pressing them between the two Petri dishes. The OCT was reached when no white core was noticed after pressing the cooked rice kernels between the two transparent Petri dishes.

2.4.3. Width expansion ratio

The width expansion ratio (WER) was determined as the ratio of the cumulative width of 10 cooked rice kernels to 10 un-cooked rice kernels.

2.5. Sensory properties

The sensory evaluation of cooked rice was conducted without any additive. In the overall evaluation, 80 panelists combining both staff (25–60years) and students (16–25years) of Landmark University, Omu-Aran with proper knowledge of polished rice were used. The 20 milled rice samples obtained during milling using the processing combinations in Tables 1 and 2 were divided randomly into four groups for 20 persons (10:10- staff to the student) per group. Each group was presented with five different coded cooked milled rice samples; they were served with 20 g each. The 20 milled rice samples were cooked differently without any additives for 20 min using the same volume of water and allowed to cool before serving the panelists for proper evaluation. The panelists were presented coded questionnaire and asked to judge the quality attributes of the rice samples in terms of flavor, aroma, appearance, texture (stickiness), and overall acceptability through a 9-point hedonic scale as shown in Table 3 (Wichchukit & O'Mahony, 2015; Devraj et al., 2019). Ethical approval was granted by Landmark University Center for Research, innovation and Development (LUCRID), and the author's herein confirm that informed consents was obtained from all patients used for these experiments.

2.6. Experimental design

The effect of independent variables; moisture content (MC), shaft speed of rotation (SR), and polishing time (PT) on the responses (milling, cooking, and sensory properties) of polished rice was studied (Tables 1 and 2). A Design Expert (version 12.0.1.0) software package was used for the experimental design, analyses, and regression model generation for the processing parameters. The experimental design adopted was 3 × 3 factorial Central Composite Face centered Design (CCFD) of response surface methodology (RSM). The CCFD consists of factorial points (n_f), axial points (n_a), and central points (n_c) (Fakayode and Abobi, 2018). Twenty (20) experiments were generated consisting of 2^3 factorial CCD, 6 axial points, and 6 replications at the center points. Quadratic, linear, two factorial interaction (2FI), and cubic models were used in the analyses and fitted to the experimental data generated to see which model performed best as suggested by Fakayode et al. (2019) and Fadale and Aremu (2018). The predicted values generated were compared with the obtained experimental data as suggested by Fakayode et al. (2019). The various ranges for each independent variable were selected based on

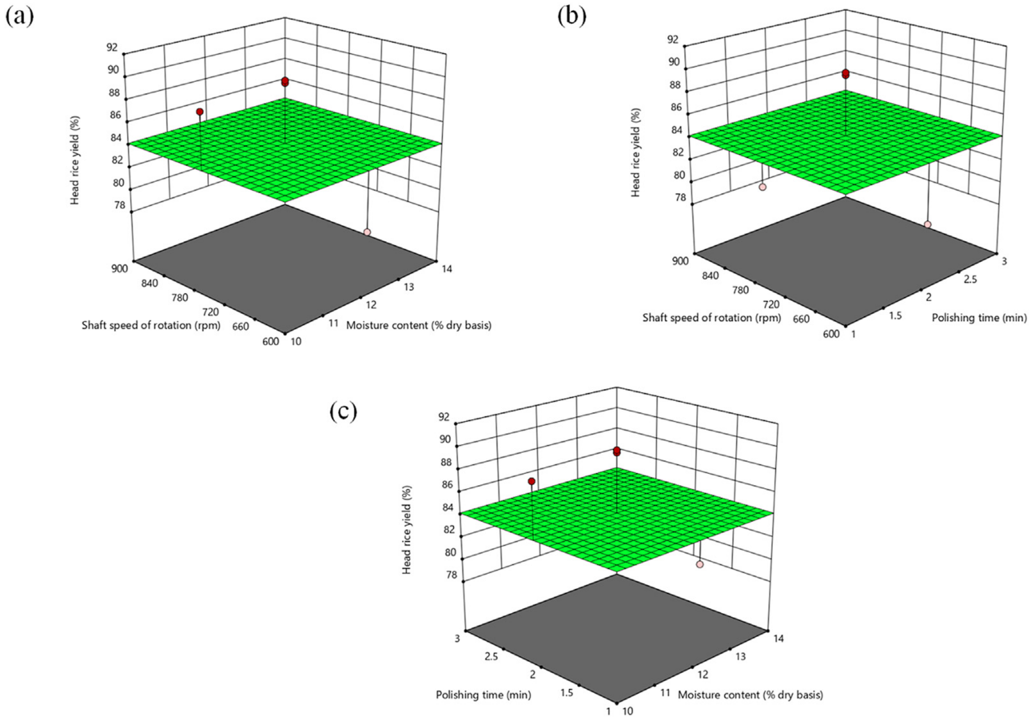

Figure 2. Response surface plots of head rice yield as against (a) moisture content versus shaft speed of rotation (b) shaft speed of rotation versus polishing time(c) moisture content versus polishing time.

preliminary experiments and literature; MC (10–14 % db), SR (600–900 rpm), and PT (1–3 min). From the design software, moisture content levels (10, 12, and 14 % db) and speed of rotation levels (600, 750, and 900 rpm), and polishing time levels (1, 2, and 3 min) were selected (Table 1).

2.7. Statistical analyses

Analysis of variance (ANOVA) and the P-value (probability of error value) generated from the Design Expert (version 12.0.1.0) software package was used to examine the significance ($P < 0.05$) of the individual and interactive independent variables. The independent variables are; MC, SR, and PT while the interactions considered were; MC versus SR, MC versus PT, and SR versus PT. The responses were milling, cooking, and sensory properties (Table 2). For P-value > 0.05, the interaction is considered not significant.

3. Results and discussion

3.1. Milling properties

The increase or decrease in the MC, SR, and polishing time (PT) did not affect the head rice yield (HRY) as observed from Figure 2 (a-c) using the developed machine. This was why the mean value was chosen instead of a model in Eq. (5). The minimum and maximum HRY obtained was 78.97 % (at 12 % db, 600 rpm, 2 min) and 90.50 % (10 % db, 600 rpm, 3 min) respectively. This signified that at the lowest MC, lowest SR, and the highest PT, HRY was maximum. Although there were no significant differences ($P > 0.05$) in the HRY across the processing variables range used. Nasirahmadi et al. (2014) reported that reduction in MC increased the HRY for Tarom and Fajr rice varieties. Also, Ahmad et al. (2017) revealed that HRY for Catahoula rice decreased with an increase in milling intensity and a maximum HRY of 89.77 % was obtained at low milling intensity. Sandhu et al. (2018) revealed that an increase in the degree of milling decreased the HRY and a maximum HRY of 69.06 % was obtained at a 2 % degree of milling. Also, Saleh and Meullenet (2013) also reported a decrease in HRY with an increase in milling duration (PT). An increase in MC (10–14 % db) increased the percentage of broken rice. This result was not similar to the behavior of the milling machine for brown rice, a decreased in the percentage of broken rice was noticed with an increase in MC. The observed difference might be due to the longer duration of paddy in the de-husking/polishing unit. Fadale and Aremu (2016) reported that there was an initial increase in the percentage of broken moringa seeds after which it decreased with further increase in MC. An increase in SR (600–900 rpm) increased the percentage of broken rice. This is as a result of a higher number of the impact caused by the de-husking/polishing shaft on the paddy during operation. This was not consistent with the findings of Sharma et al. (2013) on the shelling of Tung fruit as an increase in SR (1600–2100 rpm) resulted in increased percentage breakage. An increase in PT (1–3 min) increased the percentage of broken rice. Similar findings were reported by Ahmad et al. (2017) as the percentage of broken Catahoula rice (BR) increased as milling intensity increased and maximum BR (11.95 %) was obtained at heavy milling intensity. The interactive effect of (MC × SR), (MC × PT), and (SR× PT) increased the percentage of broken rice from 2.77 to 9.2 %, 2.77–9 %, and 2.77–8 % respectively as shown in Figure 3 (a-c). A similar result was also shown in Eq. (6). The minimum and maximum percentage of broken rice in all cases was 2.77 and 10.41 %. The maximum percentage of broken rice was lower than that reported by Adisa et al. (2016) (15.44 %), who used a two-step milling machine. An increase in MC (10–14 % db) increased the milled rice yield (MRY) from about 92.62 to 95 %. Nasirahmadi et al. (2014) reported that MRY decreased with increased MC (8–12 %). An increase in SR (600–900 rpm) increased the MRY from about 92.62 to 96.1 %. An increase in PT (1–3 min) increased the MRY from 92.62 to 96.8 %. This result was not similar to the findings by Ahmad et al. (2017) as MRY of Catahoula rice reduced with increased milling intensity. This variance might be a result of the type of milling machine used (two-step milling machine). Since in the one-step milling machine used, husking and polishing are carried out in a single run, the longer samples spend in this unit, the more head rice yield is recovered. PT was noticed to have the highest effect on the milled rice yield. The interactive effects of MC × SR, MC × PT, and SR× PT increased the MRY

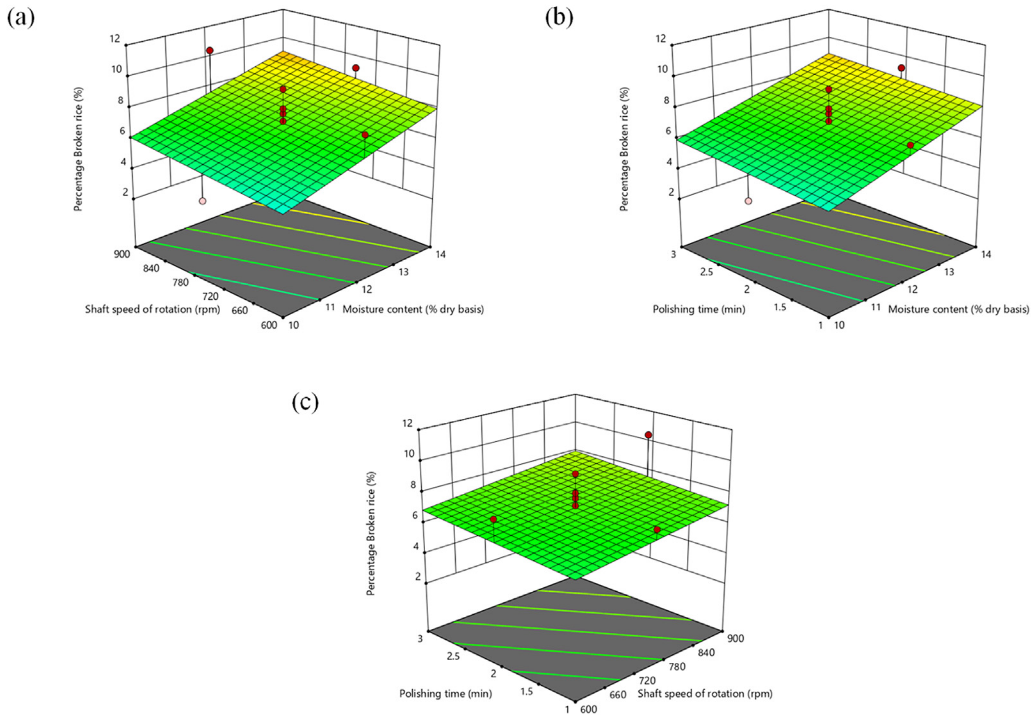

Figure 3. Response surface plots of Percentage broken rice as against (a) moisture content versus shaft speed of rotation, (b) moisture content versus polishing time, (c) shaft speed of rotation versus polishing time.

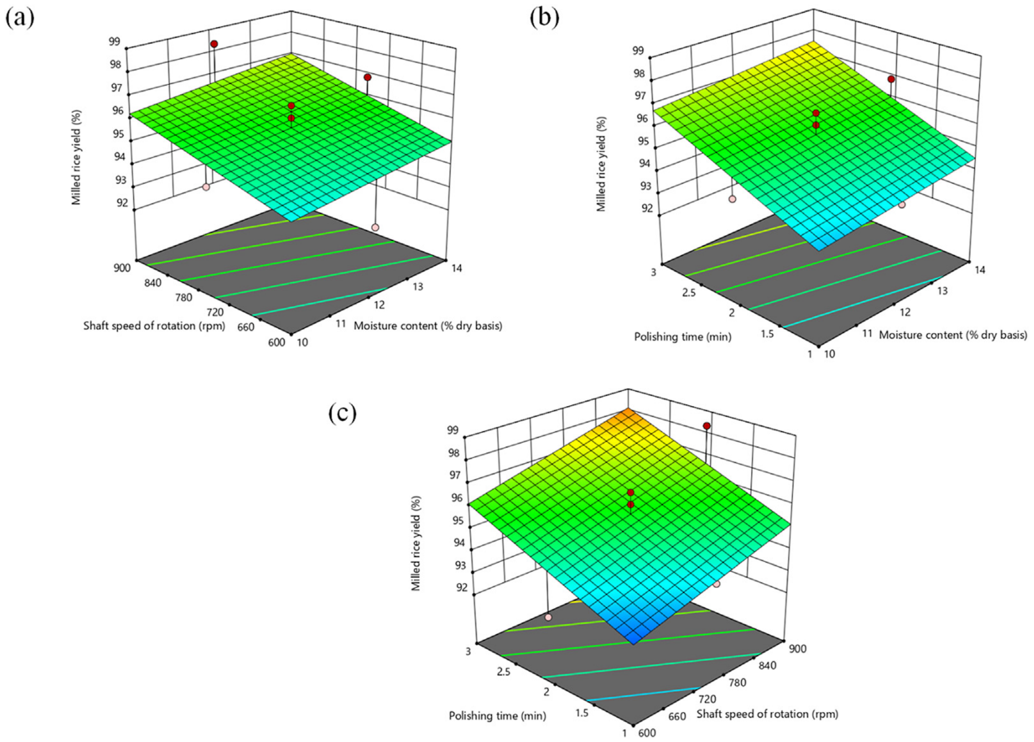

Figure 4. Response surface plots of Milled rice yield as against (a) moisture content versus shaft speed of rotation, (b) moisture content versus polishing time, (c) shaft speed of rotation versus polishing time.

from 92.62 to 97 %, 92.62–97.7 %, and 92.62–98.1 % respectively as shown in Figure 4 (a-c). This is so observed because of the mode operation of a one-step milling machine since husking and polishing occurs in a single run. The higher the moisture content the greater the ability of the rice grains to resist the impact or deformation, and the more the delay of the paddy rice at high speed in this unit the higher the HRY, PBR, and FBR which makes up the component of the MRY. The combined effect of (SR× PT) was noticed to have the highest effect on the MRY as shown in Eq. (7). The minimum and maximum values of the milled rice yield were 96.62 and 98.91 % respectively. At the same SR and PT, an increase in MC increased the percentage of fine broken rice (0.99–3.5 %) up to 12.5 % MC after which it decreased (about 3.5 to 2.5 %). Adisa et al. (2016) revealed that fine broken rice reduced with an increase in MC. At the same MC and PT, an increase in SR (600–900 rpm) increased the

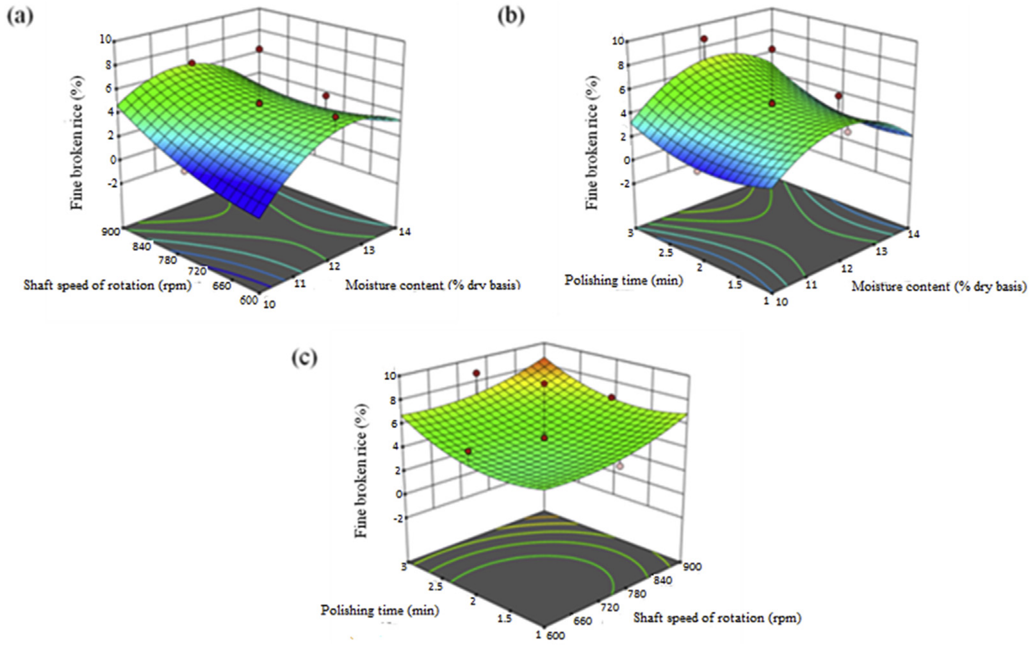

Figure 5. Response surface plots of Fine broken rice as against (a) moisture content versus shaft speed of rotation, (b) moisture content versus polishing time, (c) shaft speed of rotation versus polishing time.

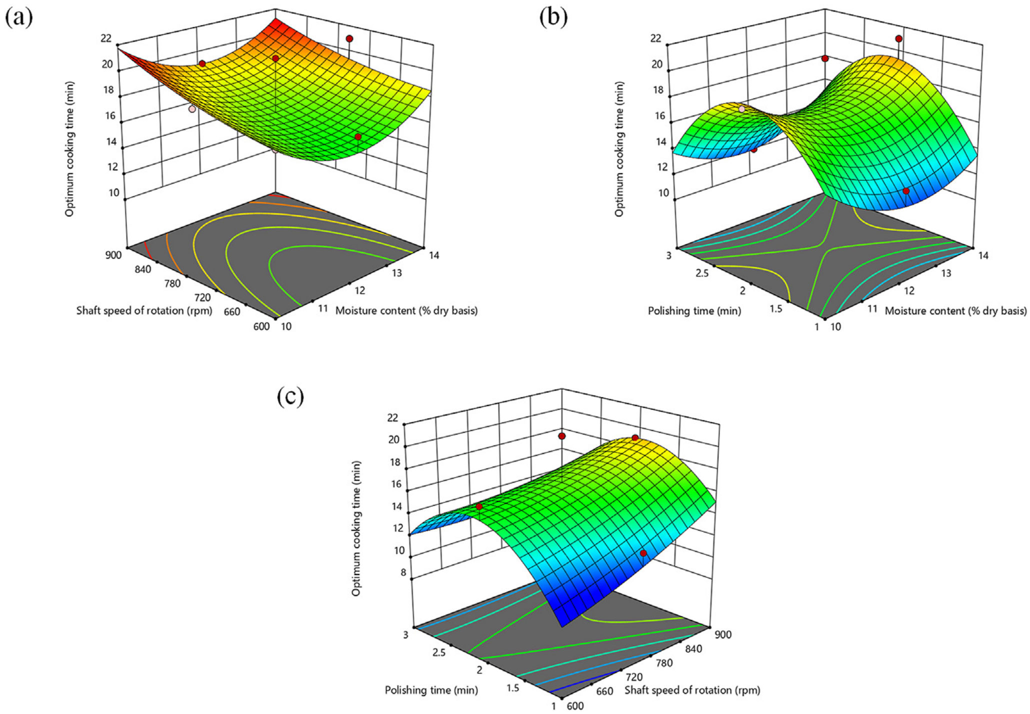

Figure 6. Response surface plots of Optimum cooking time as against (a) moisture content versus shaft speed of rotation, (b) moisture content versus polishing time, (c) shaft speed of rotation versus polishing time.

percentage of fine broken rice from 0.99 to 6.5 %. This might be due to increase impact. At the same MC and SR, an increase in PT slightly decreased the percentage of fine broken rice up to 2.25 min after which it increased. Ahmad et al. (2017) reported that fine broken Catahoula rice increased with an increase in milling intensity. The interactive effect of MC × SR, MC × PT, and SR× PT is shown in Figure 5 (a-c). A simultaneous increase in MC (10–12.5 %) and SR (600–810 rpm) increased the percentage of fine broken rice, although after MC (12.5 %) and SR (810 rpm) the percentage of fine broken rice decreased (Figure 5a). This might be as a result of the one-step milling machine used; it also shows that MC below 12.5 % is more affected by the high-speed impact of the shaft in the milling machine, causing a high percentage of fine broken rice. De Figueiredo et al. (2013) reported that percentage fines of safflower seeds increased with an increase in MC and SR. A decrease in MC with an increase in SR above the optimum increased the fine broken rice. At low SR, an increase in MC up to 12.5 % increased the percentage of fine broken rice after which it decreased. An increase in MC and PT increased the percentage of fine broken rice. This is due to the longer milling duration. At low MC increase in PT increased the fine broken rice, while at reduced PT increase in MC up to 12.5 % increased the percentage of fine broken rice after which further increase in the MC led to a decrease in the fine broken rice. An increase in PT and SR increased the percentage of fine broken rice. At low SR increase in PT increased the fine broken rice, while at reduced PT increase in SR increased the fine broken rice. This result was also observed in Eq. (8). The minimum and maximum values for the fine broken rice were 0.99 and 9.39 %, of which the PT and the SR were observed to increase the percentage of fine broken rice the most.

3.2. Cooking properties

At the same SR and PT levels, MC decreased the optimum cooking time (OCT) up to about 12 %, after which it increased (Figure 6 (a-b)). This might be because at low moisture more time is required for the starch molecules in rice grain to absorb moisture and cook as compared to high MC. At the same MC and PT levels, an increase in SR increased the OCT (Figure 6 (a, c)). This might be due to more mechanical impact experienced by rice grains as a result of high speed. At the same SR and MC levels, PT increased the OCT up to about 2.25 min, after which it decreased (Figure 6 (b-c)). The OCT of rice depends on the rate of moisture diffusion. The decrease in cooking time might be attributed to the removal of the bran layer during polishing thereby increasing the rate of moisture diffusion to the starch molecule. It can also be a result of differences in starch gelatinization temperature, rice with high gelatinization temperature uses a longer duration during cooking than those with low gelatinization temperature. Similar findings were reported by Sandhu et al. (2018), Mohapatra and Bal (2007), and Rosniyana et al. (2006), as cooking time decreased with an increase in the degree of milling for both long and short rice cultivars. Monks et al. (2013) noticed that for a two-step milling process, cooking time decreased when milling brown rice to polished rice, but across the polished rice cooking time was constant. The interactive effect of MC × SR, MC × PT, and SR× PT is shown in Figure 6 (a-c). An increase in MC and SR increased the OCT. At low SR increase in MC decreased the OCT up to 12 % and increased afterward, whereas at low MC increased SR increased the OCT (Figure 6a). An increase in MC and PT increased the OCT up to when the PT and MC were 2.25 min and 12.5 % respectively, after which the OCT cooking time decreased. In a one-step milling machine, husking and polishing occur in a single run, at an increase MC husking becomes difficult, thereby preventing polishing from taking place. This might be the reason for increased OCT. At low MC, an increase in the PT increased the OCT up to 2.25 min, after which there was a decrease. Whereas at low PT, an increase in MC led to a decrease in the OCT up to 12.4 % after which it increased (Figure 6b). An increase in PT and SR increased the OCT up to SR (780 rpm) and PT (2.25 min) after which there was a slight decrease in OCT. At low SR, an increase in PT increased the OCT up to 2.25 min, after which it decreased, likewise at low PT, increased SR increased the OCT (Figure 6c) and Eq. (9). The decrease in OCT after 2.25 min shows that the bran layer was diminished, allowing a higher rate of moisture diffusion to the starchy endosperm. Lower SR signifies a lesser number of impacts of the husking cum polishing shaft on the paddy rice. Since a

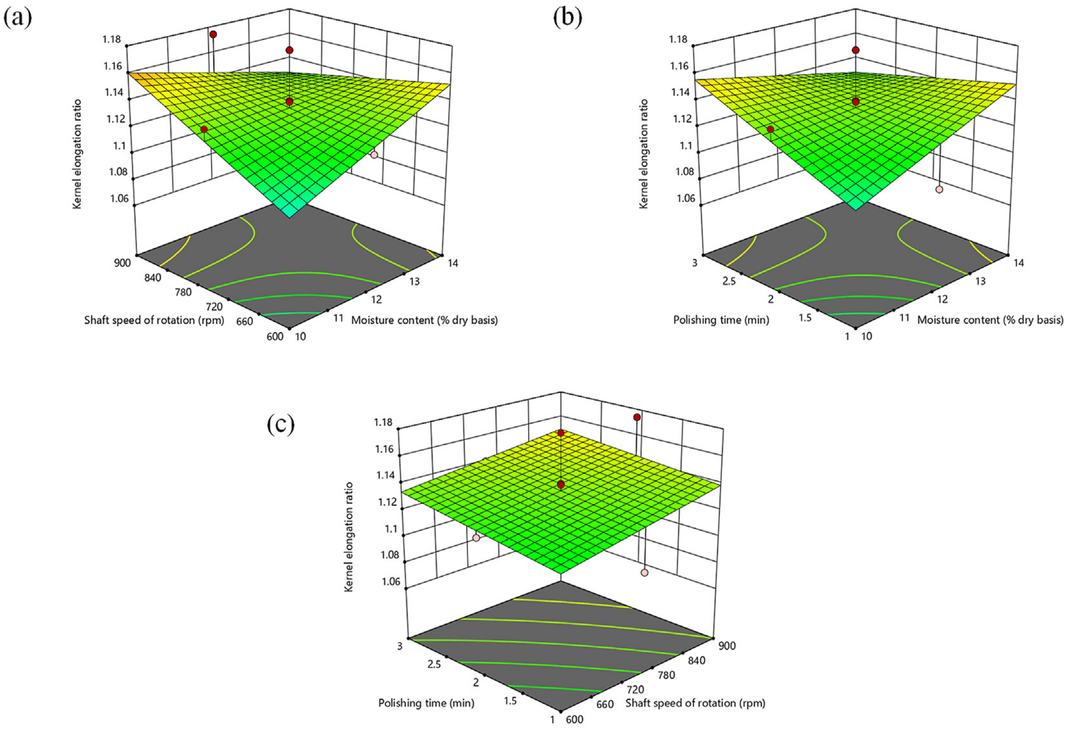

Figure 7. Response surface plots of Kernel elongation ratio as against (a) moisture content versus shaft speed of rotation, (b) moisture content versus polishing time (c) shaft speed of rotation versus polishing time.

one-step milling machine was used where husking and polishing take place in the same unit, polishing only occurs after the husking operation. Therefore a delay in husking operation causes a low polishing degree. These findings for the OCT were similar to Eq. (9). The minimum and maximum values for the OCT were 11 and 21 min respectively. Mohapatra and Bal (2007) reported a cooking time of 14, 18, and 21 min at an optimum degree of milling for Pusa Basmati, Swarna, and ADT37 rice cultivars respectively. Sandhu et al. (2018) reported a cooking time between the range of 14.06 and 16.3 min for PR113 and 12.04 and 13.23 min for PUSAI121. Singh et al. (2005) on the cooking properties of milled rice from Indian cultivars, reported a minimum and maximum cooking time of 13.3 and 24 min. At the same SR and PT levels, an increase in MC

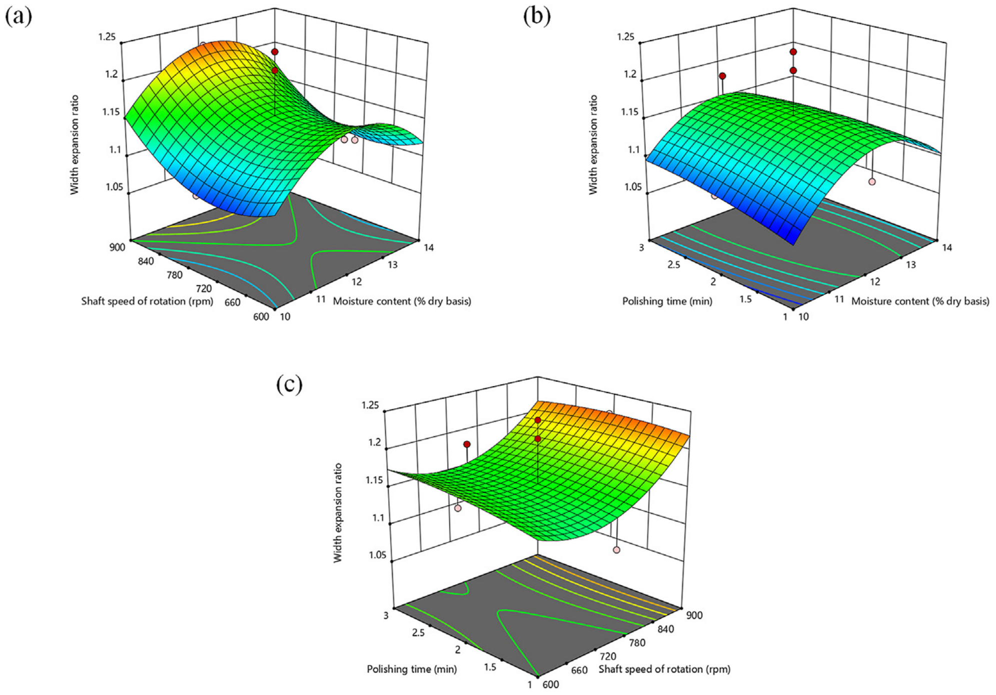

Figure 8. Response surface plots of width expansion ratio as against (a) moisture content versus shaft speed of rotation, (b) moisture content versus polishing time (c) shaft speed of rotation versus polishing time.

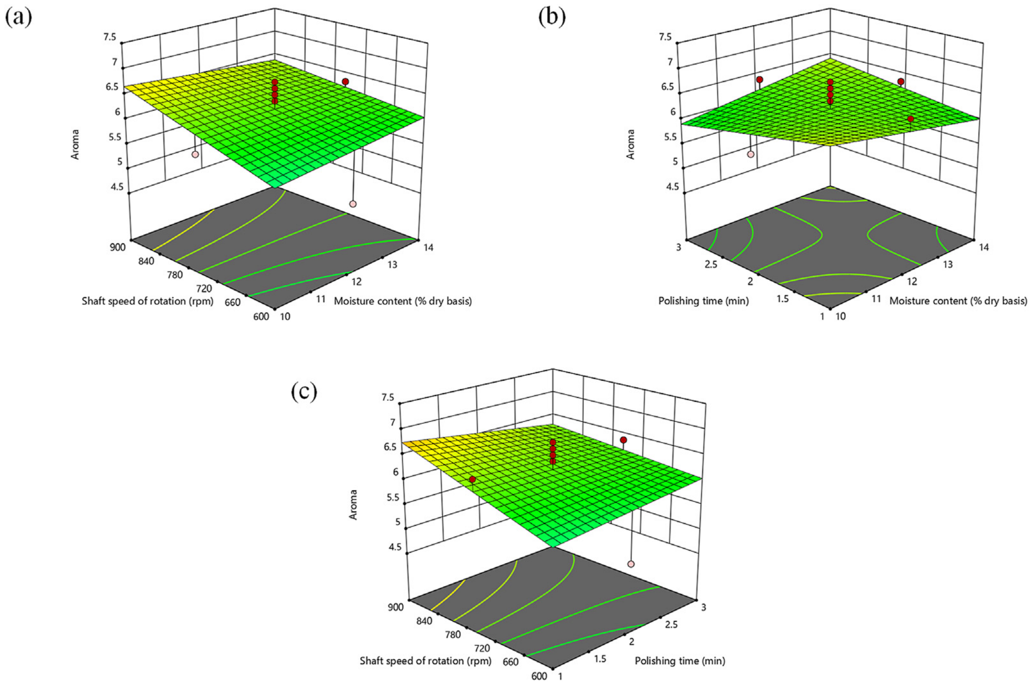

Figure 9. Response surface plots of Aroma as against (a) moisture content versus shaft speed of rotation, (b) moisture content versus polishing time, (c) shaft speed of rotation versus polishing time.

increased the kernel elongation ratio (KER) (Figure 7 (a-b). Also at the same MC and PT, an increase in SR increased the KER (Figure 7 (a, c)). This might be because at high MC the mechanical impact created by the high-speed de-husking shaft distorts the properties and structure of the rice grain. At high moisture, rice grains' undergoing increased impact tend to behave like ductile material, thereby increasing in length or width, which contributes to the elongation during cooking. At the same SR and MC, an increase in PT increased the KER (Figure 7 (b-c)). This is as a result of an increase in the number of impacts experienced at high polishing duration, causing more rice grains to be distorted either in length or width, leading to higher elongation during cooking. This result was consistent with Sandhu et al. (2018) as they reported that KER increased with an increase in the degree of milling. Also, Rosniyana et al. (2006) and Mohapatra and Bal (2007) revealed that elongation ratio or cooking index increased with an increase in the degree of milling. The interactive effect of MC × SR, MC × PT, and SR× PT is shown in Figure 7 (a-c). An increase in MC and SR increased the KER. At low SR increase in MC increased the KER, whereas at low MC increased SR increased the KER (Figure 7a). Increased MC and PT led to an increase in the KER. At low MC, an increase in the PT increased the KER, while at low PT; increased MC increase the KER (Figure 7b). An increase in PT as against SR increased the KER. At low SR increase in PT increased the KER; likewise at low PT increased SR increased the KER (Figure 7c). These findings for the OCT were similar to Eq. (10). The minimum and maximum values for the KER were 1.06 and 1.18 respectively of which the PT and the SR increased the KER the most. The minimum and maximum rice cultivars KER reported by several researchers; Singh et al. (2005), Sandhu et al. (2018), Rosniyana et al. (2006), Kaur et al. (2011) ranged between 1.29-2.21. At the same SR and PT, an increase in MC increased the width expansion ratio (WER) up to about MC (13.5 %), after which it slightly decreased (Figure 8 (a-b). At the same MC and PT, an increase in SR increased the WER (Figure 8 (a, c)). At the same SR and MC levels, an increase in PT increased the WER (Figure 8 (b-c)). The interactive effect of MC × SR, MC × PT, and SR× PT is shown in Figure 8 (a-c). These indicate that the pericarp and seed coat enclosed in the bran layer acted as a barrier that controlled moisture penetration to the starch molecules. An increase in MC and SR increased the WER. At low SR, an increase in MC increased the WER up to MC (13.5 %), and after which the WER decreased with further increase in MC. At low MC, an increase in SR decreased the WER up to SR (720 rpm), after which further increase in the SR increased the WER (Figure 8a). An increase in MC and PT increased WER up to PT (2.25 min), beyond which there was a decrease in WER. At low MC, an increase in the PT increased the WER. At low PT, an increase in MC increased the WER up to MC (13.5 %), after which it decreased (Figure 8b). An increase in PT as against SR increased the WER. At low SR, an increase in PT increased the WER, likewise at low PT, increased SR decreased the WER up to SR (720 rpm), after which it increased (Figure 8c). These findings for the OCT were similar to Eq. (11). The minimum and maximum values for the WER were 1.07 and 1.24 respectively of which the PT and the SR increased the WER the most. An elongation ratio less than 2 showed that this rice variety did not expand. Expansion of rice during cooking varies for different cultivars (Rosniyana et al., 2006).

3.3. *Sensory evaluation*

At the same SR and PT levels, MC increased the aroma (Figure 9 (a-b)). At the same MC and PT levels, SR increased the aroma (Figure 9 (a, c)). At the same SR and MC levels, an increase in PT decreased the aroma (Figure 9 (b-c)) also as shown in Eq. (12). This means that the rice aroma is embedded in the bran layer. A similar finding was reported by Rodríguez-Arzuaga et al. (2015) as aroma reduced with an increase in the degree of milling. The interactive effects of MC × SR, MC × PT, and SR× PT are shown in Figure 9 (a-c). An increase in MC and SR increased the aroma. At low SR increase in MC increased the aroma, whereas at low MC increase in SR increased the aroma (Figure 9a). An increase in MC and PT increased the aroma. At low MC, an increase in the PT decreased the aroma. Whereas, at low PT increase in MC increased the aroma (Figure 9b). An increase in PT and SR increased the aroma. At high SR, an increase in PT decreased the aroma. At low PT, an increase in SR

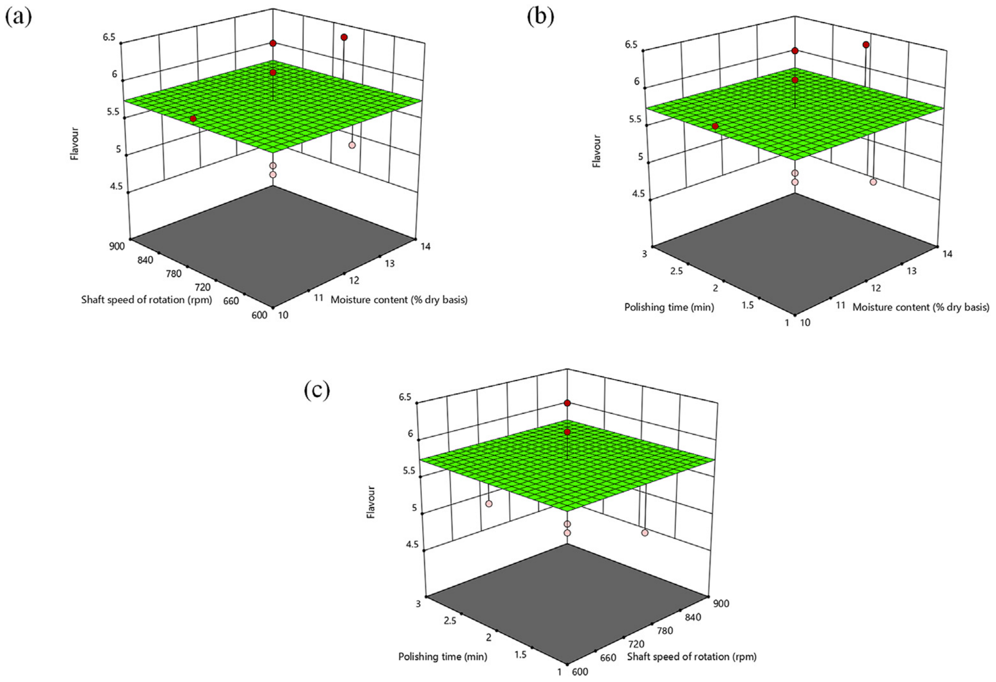

Figure 10. Response surface plots of Flavour as against (a) moisture content versus shaft speed of rotation, (b) moisture content versus polishing time, (c) shaft speed of rotation versus polishing time.

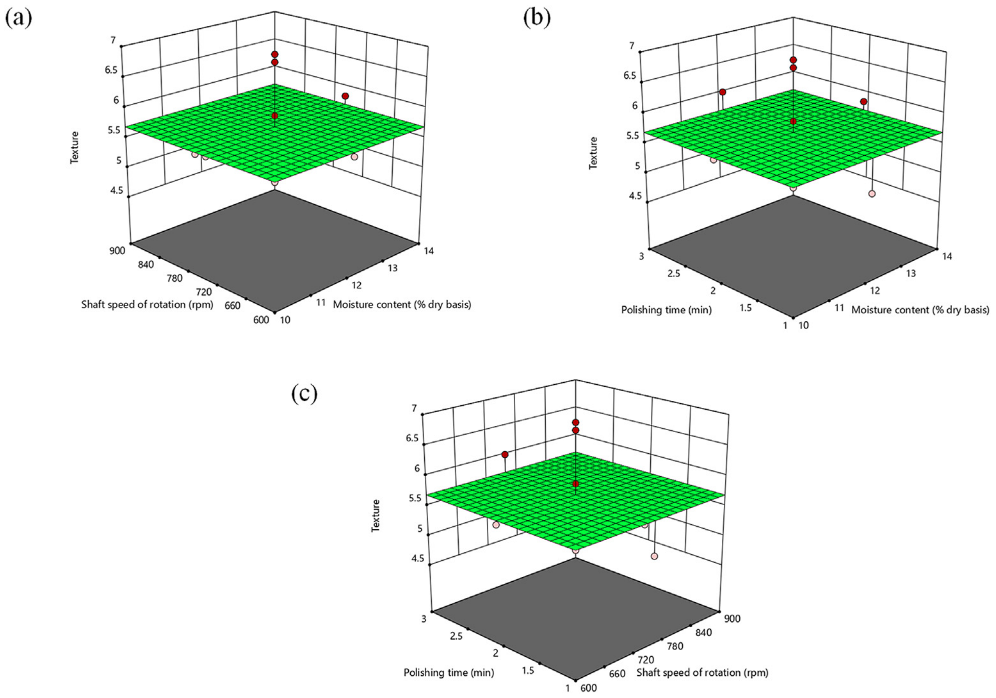

Figure 11. Response surface plots of Texture as against (a) moisture content versus shaft speed of rotation, (b) moisture content versus polishing time, (c) shaft speed of rotation versus polishing time.

increased the aroma (Figure 9c). The decrease in aroma with an increase in PT experienced at high SR is due to more of the bran layer that was removed. The rice aroma is embedded in the bran; therefore reduction of the bran layer reduces the aroma value. This also signifies that the aroma value of rice grains is reduced by only the PT. The minimum and maximum scores for the aroma were approximately 5 and 7 respectively. The maximum score was lower in comparison to a score of 9 reported by Devraj et al. (2019) and Simonelli et al. (2017) for white rice, probably due to varietal difference. At the same SR and PT levels, an increase in MC did not affect the flavor (Figure 10 (a-b)). At the same MC and PT levels, an increase in SR did not affect the flavor (Figure 10 (a, c)). At the same SR and MC levels, an increase in PT did not affect the flavor (Figure 10 (b-c)). The interactive effect of MC × SR, MC × PT, and SR× PT did not affect the flavor as shown in Figure 10 (a-c). This is also demonstrated in Eq. (13), which resulted in why a mean value was selected instead of a model. The minimum and maximum value for the

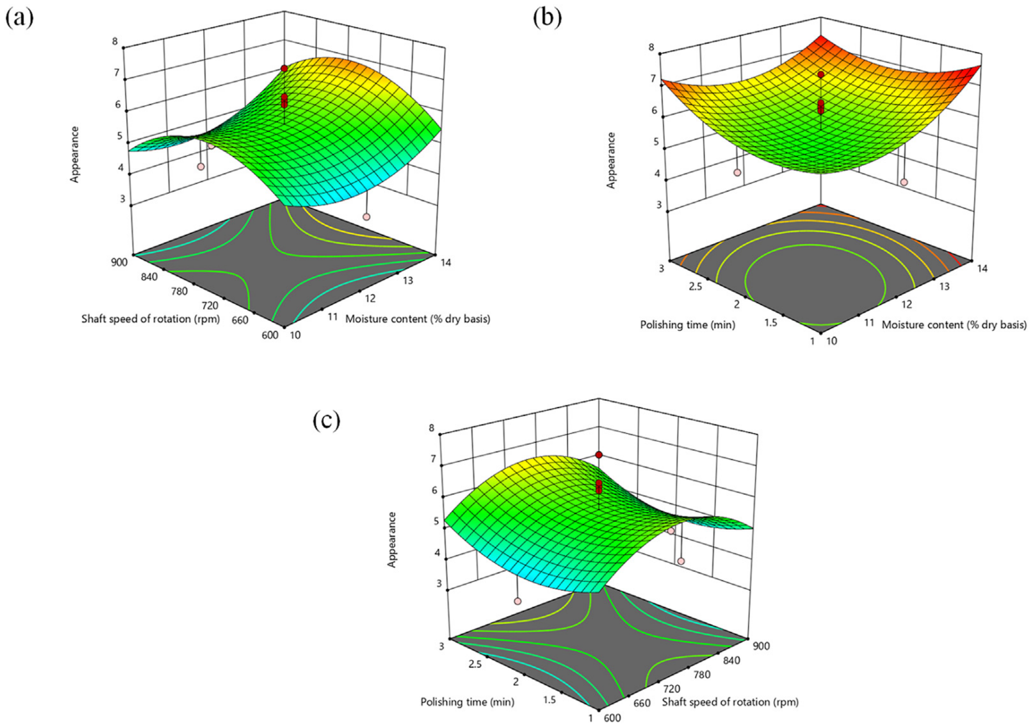

Figure 12. Response surface plots of appearance as against (a) moisture content versus shaft speed of rotation, (b) moisture content versus polishing time, (c) shaft speed of rotation versus polishing time.

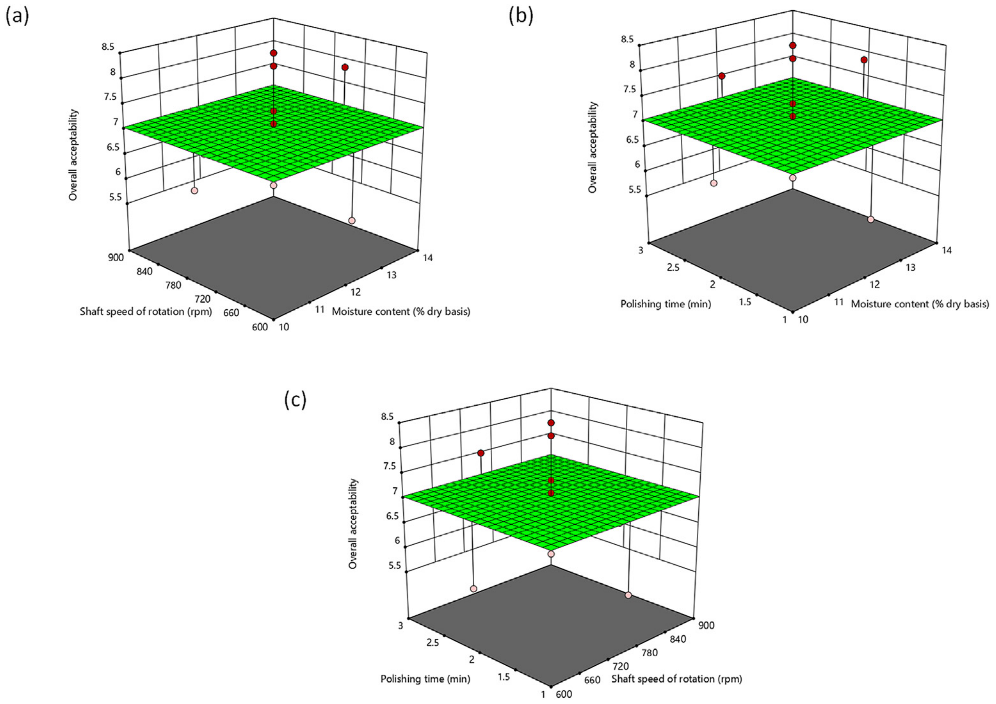

Figure 13. Response surface plots of overall acceptability as against (a) moisture content versus shaft speed of rotation, (b) moisture content versus polishing time (c) shaft speed of rotation versus polishing time.

flavor as predicted by consumers was approximately 5 and 7 respectively. This observation was not in agreement with Devraj et al. (2019), who reported that the sensory score of flavor for white rice was higher than that of traditional brown rice. At the same SR and PT levels, an increase in MC did not affect the texture (Figure 11 (a-b). At the same MC and PT levels, an increase in SR did not affect the texture (Figure 11 (a, c)). At the same SR and MC levels, an increase in PT did not affect the texture (Figure 11 (b-c)). This was also supported by Eq. (14), anda mean value was selected instead of a model. This observed result might be due to the rice cultivar. Zhong et al. (2013) reported an increase in stickiness with

Table 4. ANOVA for response surface models for the milling properties, cooking properties, and sensory properties.

Source	SS	Df	MS	F-value	p > F
Head rice yield (Mean)					
Model	0.0000	0	-	-	-
Residual	234.72	19	12.35	-	-
Lack of Fit	136.84	14	9.77	0.4993	0.8594
Pure Error	97.87	5	19.57	-	-
Cor Total	234.72	19	-	-	-
Percentage broken rice (Linear)					
Model	26.94	3	8.98	2.36	0.1100
A	22.31	1	22.31	5.86	0.0277
B	3.12	1	3.12	0.8190	0.3789
C	1.52	1	1.52	0.3983	0.5369
Residual	60.91	16	3.81	-	-
Lack of Fit	27.81	11	2.53	0.3820	0.9148
Pure Error	33.10	5	6.62	-	-
Cor Total	87.85	19	-	-	-
Milled rice yield (Linear)					
Model	33.37	3	11.12	7.11	0.0030
A	1.49	1	1.49	0.9532	0.3434
B	9.79	1	9.79	6.26	0.0236
C	22.09	1	22.09	14.11	0.0017
Residual	25.04	16	1.56	-	-
Lack of Fit	19.62	11	1.78	1.65	0.3039
Pure Error	5.42	5	1.08	-	-
Cor Total	58.40	19	-	-	-
Fine broken rice (Quadratic)					
Model	59.02	9	6.56	1.21	0.3834
A	1.41	1	1.41	0.2604	0.6209
B	10.11	1	10.11	1.86	0.2021
C	8.89	1	8.89	1.64	0.2294
AB	14.82	1	14.82	2.73	0.1293
AC	1.78	1	1.78	0.3283	0.5793
BC	0.0129	1	0.0129	0.0024	0.9621
A^2	21.78	1	21.78	4.02	0.0729
B^2	1.77	1	1.77	0.3265	0.5803
C^2	4.37	1	4.37	0.8058	0.3905
Residual	54.23	10	5.42	-	-
Lack of Fit	9.64	5	1.93	0.2161	0.9410
Pure Error	44.59	5	8.92	-	-
Cor Total	113.25	19	-	-	-
Optimum cooking time (Quadratic)					
Model	118.20	9	13.13	3.69	0.0270
A	0.0000	1	0.0000	0.0000	1.0000
B	25.60	1	25.60	7.19	0.0230
C	0.1000	1	0.1000	0.0281	0.8702
AB	0.5000	1	0.5000	0.1404	0.7157
AC	4.50	1	4.50	1.26	0.2872
BC	12.50	1	12.50	3.51	0.0904
A^2	17.19	1	17.19	4.83	0.0527
B^2	0.6875	1	0.6875	0.1931	0.6697
C^2	68.75	1	68.75	19.31	0.0013
Residual	35.60	10	3.56	-	-
Lack of Fit	8.10	5	1.62	0.2945	0.8971
Pure Error	27.50	5	5.50	-	-
Cor Total	153.80	19	-	-	-
Kernel elongation ratio (2FI)					
Model	0.0083	6	0.0014	3.25	0.0354
A-MC	0.0003	1	0.0003	0.7079	0.4153
B-SR	0.0009	1	0.0009	2.16	0.1657

(*continued on next page*)

Table 4 (*continued*)

Source	SS	Df	MS	F-value	p > F
C-PT	0.0005	1	0.0005	1.18	0.2971
AB	0.0037	1	0.0037	8.65	0.0115
AC	0.0029	1	0.0029	6.76	0.0220
BC	0.0000	1	0.0000	0.0421	0.8406
Residual	0.0056	13	0.0004	-	-
Lack of Fit	0.0043	8	0.0005	2.14	0.2090
Pure Error	0.0013	5	0.0003	-	-
Cor Total	0.0139	19	-	-	-
Width expansion ratio (Quadratic)					
Model	0.0220	9	0.0024	1.30	0.3434
A	0.0008	1	0.0008	0.4402	0.5220
B	0.0070	1	0.0070	3.70	0.0832
C	0.0002	1	0.0002	0.1076	0.7496
AB	1.250E-07	1	1.250E-07	0.0001	0.9937
AC	0.0010	1	0.0010	0.5263	0.4848
BC	0.0003	1	0.0003	0.1595	0.6980
A^2	0.0100	1	0.0100	5.32	0.0438
B^2	0.0047	1	0.0047	2.48	0.1465
C^2	0.0001	1	0.0001	0.0584	0.8140
Residual	0.0188	10	0.0019	-	-
Lack of Fit	0.0042	5	0.0008	0.2869	0.9016
Pure Error	0.0146	5	0.0029	-	-
Cor Total	0.0408	19	-	-	-
Aroma (2FI)					
Model	1.90	6	0.3159	1.85	0.1665
A-MC	0.0003	1	0.0003	0.0017	0.9677
B-SR	0.9600	1	0.9600	5.61	0.0340
C-PT	0.0209	1	0.0209	0.1220	0.7325
AB	0.1610	1	0.1610	0.9412	0.3497
AC	0.5008	1	0.5008	2.93	0.1108
BC	0.2523	1	0.2523	1.47	0.2462
Residual	2.22	13	0.1711		
Lack of Fit	1.62	8	0.2021	1.67	0.2977
Pure Error	0.6068	5	0.1214		
Cor Total	4.12	19			
Flavour (Mean)					
Model	0.0000	0	-	-	-
Residual	4.83	19	0.2540	-	-
Lack of Fit	1.99	14	0.1423	0.2512	0.9814
Pure Error	2.83	5	0.5667	-	-
Cor Total	4.83	19	-	-	-
Texture (Mean)					
Model	0.0000	0	-	-	-
Residual	6.83	19	0.3596	-	-
Lack of Fit	2.73	14	0.1947	0.2371	0.9849
Pure Error	4.11	5	0.8214	-	-
Cor Total	6.83	19	-	-	-
Appearance (Quadratic)					
Model	2.04	1	2.04	2.22	0.1673
A	0.1064	1	0.1064	0.1155	0.7410
B	0.5609	1	0.5609	0.6085	0.4534
C	0.2933	1	0.2933	0.3182	0.5851
AB	1.07	1	1.07	1.17	0.3056
AC	0.0076	1	0.0076	0.0082	0.9296
BC	1.67	1	1.67	1.81	0.2078
A^2	3.30	1	3.30	3.58	0.0878
B^2	1.18	1	1.18	1.28	0.2845
C^2	9.22	10	0.9217	-	-
Residual	4.91	5	0.9830	1.14	0.4437

(*continued on next page*)

Table 4 (*continued*)

Source	SS	Df	MS	F-value	p > F
Lack of Fit	4.30	5	0.8604	-	-
Pure Error	18.12	19	-	-	-
Cor Total	8.90	9	0.9893	1.07	0.4531
Overall acceptability (Mean)					
Model	0.0000	0	-	-	-
Residual	13.88	19	0.7305	-	-
Lack of Fit	8.40	14	0.5998	0.5471	0.8282
Pure Error	5.48	5	1.10	-	-
Cor Total	13.88	19	-	-	-

A-moisture content, B-shaft speed of rotation, C-polishing time (min), Df = degree of freedom, MS = mean square, SS = sum of square, Values of "p > F" < 0.05 indicate model terms are significant.

an increased degree of milling. The interactive effects of MC × SR, MC × PT, and SR× PT did not affect the texture as shown in Figure 11 (a-c). The minimum and maximum value for the texture as predicted by consumers was approximately 5 and 7 respectively. At the same SR and PT levels, an increase in MC decreased the appearance up to about 11 % MC, after which it increased (Figure 12 (a-b)). At the same MC and PT levels, an increase in SR increased the appearance up to SR (780 rpm), after which it decreased (Figure 12 (a, c)). At the same SR and MC levels, an increase in PT increased the appearance (Figure 12 (b-c)). This was parallel to the result of Zhong et al. (2013) and Rodríguez-Arzuaga et al. (2015), as appearance increased with an increase in milling degree. The interactive effects of MC × SR, MC × PT, and SR× PT for the consumer's prediction of the appearance are shown in Figure 12 (a-c). An increase in MC and SR increased the appearance. At low SR, an increase in MC decreased the appearance up to about 11 % MC and decreased afterward. Whereas, at low MC increase in SR increased the appearance up to SR (780 rpm), and decreased afterward (Figure 12a). An increase in MC and PT increased the appearance of the rice grains. At low MC, an increase in the PT increased the appearance. At low PT, an increase in MC increased the appearance (Figure 12b). Increased PT as against SR increased the appearance. At low SR, an increase in PT increased the appearance, whereas at low PT increase in SR increased the appearance up to SR (780 rpm) and decreased afterward (Figure 12c). The minimum and maximum values for the appearance were approximately 4 and 7 respectively. This observed result was also demonstrated in Eq. (15). Zhong et al. (2013) reported a minimum and maximum appearance score of 4 and 6 respectively. At the same SR and PT levels, an increase in MC did not affect overall acceptability (Figure 13 (a-b). At the same MC and PT levels, an increase in SR did not affect overall acceptability (Figure 13 (a, c)). This is also supported by Eq. (16), anda mean value was selected instead of a model. At the same SR and MC levels, an increase in PT did not affect overall acceptability (Figure 13 (b-c)). The interactive effect of MC × SR, MC × PT, and SR× PT did not affect the overall acceptability as shown in Figure 13 (a-c). The minimum and maximum value for the texture as predicted by consumers was approximately 6 and 9 respectively. Devraj et al. (2019) and Simonelli et al. (2017) reported an increase in the sensory scores of white rice over brown rice. A maximum sensory score of 9 was reported.

3.4. Modeling of the milling, cooking, and sensory properties

Linear, quadratic, cubic, and 2-factor interaction (2FI) models were individually adapted for the quality parameters.

$$HRY = 84.24119 \tag{5}$$

$$BR = -5.488 + 0.747*MC + 0.004*SR + 0.389*PT \tag{6}$$

$$MRY = 85.401 + 0.193*MC + 0.007*SR + 1.486*PT \tag{7}$$

$$FBR = -116.231 + 20.006*MC + 0.008*SR - 6.730*PT - 0.005*MC*SR + 0.236*MC*PT - 0.0003*SR*PT - 0.704MC^2 + 0.00004SR^2 + 1.261PT^2 \tag{8}$$

$$OCT = 80.2 - 15.125*MC + 0.004*SR + 21.85*PT - 0.0008*MC*SR + 0.375*MC*PT - 0.008*SR*PT + 0.625MC^2 + 0.00002SR^2 - 5.0PT^2 \tag{9}$$

$$KER = 0.152 + 0.0755*MC + 0.0009*SR + 0.129*PT - 0.00007*MC*SR - 0.0095*MC*PT \tag{10}$$

$$WER = -0.398 + 0.377*MC - 0.002*SR + 0.127*PT + 4.166E - 07*MC*SR - 0.006*MC*PT - 0.00004*SR*PT - 0.015MC^2 + 1.83E - 06SR^2 - 0.006PT^2 \tag{11}$$

$$Aroma = 1.696 + 0.107*MC + 0.010*SR - 0.659*PT - 0.0005*MC*SR + 0.125*MC*PT - 0.0012*SR*PT \tag{12}$$

$$Flavour = 5.753 \tag{13}$$

$$Texture = 5.690 \tag{14}$$

$$Appearance = 6.897 - 4.565*MC + 0.0656*SR - 0.337*PT + 0.0006*MC*SR - 0.183*MC*PT + 0.0002*SR*PT + 0.195MC^2 - 0.00005SR^2 + 0.655PT^2 \tag{15}$$

$$Overall\ acceptability = 7.055 \tag{16}$$

Where,

MC = moisture content (% dry basis), SR = shaft speed of rotation (rpm), PT = polishing time (min), FBR = fine broken rice (%).

Model F-values for the HRY, BR, MRY, FBR, OCT, KER, WER, aroma, flavor, texture, appearance, and overall acceptability were 0, 2.36, 7.11, 1.21, 3.69, 3.25, 1.30, 1.85, 0, 0, 1.07, and 0 respectively (Table 4). These F-values of the models for MRY, OCT, and KER were significant ($P < 0.05$) indicating significant models with only a 0.05 % chance that an F-value this large could occur due to noise. Whereas, for HRY, BR, FBR, WER, Aroma, flavor, texture, appearance, and overall acceptability the models were not significant ($P > 0.05$). Significant model terms are indicated by $p > F$ less than 0.05. The significant model terms were MRY

Table 5. Model selection for milling properties, cooking properties, and sensory properties.

	Linear	2FI	Quadratic	Cubic	Linear	2FI	Quadratic	Cubic
	Head rice yield				Percentage broken rice			
SD	3.62	3.68	3.53	4.30	1.92	2.01	2.07	2.44
R^2	0.1088	0.2515	0.4705	0.5267	0.3067	0.4026	0.5124	0.5939
Mean	84.24	84.24	84.24	84.24	7.04	7.04	7.04	7.04
Adj. R^2	-0.0583	-0.0939	-0.0061	-0.4988	0.1767	0.1269	0.0736	-0.2859
C.V.	4.29	4.36	4.19	5.11	27.70	28.52	29.38	34.61
Pred. R^2	-0.3089	-0.5262	-0.3003	-68.7141	0.0387	0.0585	-0.2610	-35.5374
PRESS	307.22	358.24	305.20	16363.18	84.46	82.71	110.78	3209.92
Adeq. Prec.	2.7353	3.7655	3.4984	2.8275	5.5959	5.0588	4.1090	3.2734
	Milled rice yield				Percentage dockages			
SD	1.25	1.31	1.29	0.9512	2.41	2.42	2.33	2.84
R^2	0.5713	0.6173	0.7138	0.9070	0.1802	0.3269	0.7268	0.9041
Mean	95.64	95.64	95.64	95.64	4.35	4.35	4.35	4.35
Adj. R^2	0.4909	0.4406	0.4563	0.7056	0.0265	0.0162	0.0902	-0.3517
C.V.	1.31	1.37	1.35	0.9946	55.35	55.64	53.51	65.22
Pred. R^2	0.3037	-0.6167	-0.7004	0.6986	-0.2008	-0.1926	-0.0590	-40.1975
PRESS	40.67	94.42	99.31	17.60	136	135.07	119.94	186.41
Adeq. Prec.	10.2307	8.3371	7.0749	7.8535	4.3141	3.9610	3.77	3.1046
	Optimum cooking time				Kernel elongation ratio			
SD	2.83	2.92	1.89	2.27	0.0276	0.0207	0.0203	0.0165
R^2	0.1671	0.2809	0.7685	0.7997	0.1244	0.6	0.7027	0.8822
Mean	15.90	15.90	15.90	15.90	1.13	1.13	1.13	1.13
Adj. R^2	0.0109	-0.0510	0.5602	0.3658	-0.0397	0.4154	0.4351	0.6270
C.V.	17.80	18.34	11.87	14.25	2.43	1.83	1.79	1.45
Pred. R^2	-0.2877	-0.8612	0.3875	-25.5936	-0.7114	-0.3542	-1.0967	-32.7153
PRESS	198.05	286.25	94.21	177.39	0.0238	0.0188	0.0291	0.4682
Adeq. Prec.	2.6869	4.1725	5.9588	4.8797	3.6015	9.3545	7.9624	8.6175
	Width expansion ratio				Aroma			
SD	0.0453	0.0492	0.0434	0.0502	0.4429	0.4136	0.3940	0.3840
R^2	0.1961	0.2277	0.5388	0.6293	0.2382	0.4601	0.6231	0.7852
Mean	1.14	1.14	1.14	1.14	6.22	6.22	6.22	6.22
Adj. R^2	0.0454	-0.1287	0.1238	-0.1738	0.0954	0.2109	0.2839	0.3197
C.V.	3.96	4.31	3.79	4.39	7.13	6.65	6.34	6.18
Pred. R^2	-0.0856	-0.6007	-0.4696	-14.6164	0.0954	-0.1679	-0.8538	-82.1650
PRESS	0.0443	0.0653	0.06	0.6371	5.20	4.81	7.64	342.56
Adeq. Prec.	3.9512	3.6224	4.8960	3.7440	3.6447	6.1104	5.8246	6.4545
	Flavour				Texture			
SD	0.5469	0.5856	0.5595	0.6903	0.6455	0.6784	0.7505	0.8560
R^2	0.0082	0.0763	0.3514	0.4076	0.0242	0.1244	0.1756	0.3566
Mean	5.75	5.75	5.75	5.75	569	5.69	5.69	5.69
Adj. R^2	-0.1778	-0.35	-0.2323	-0.8760	-0.1587	-0.2797	-0.5664	-0.0375
C.V.	9.51	10.18	9.72	12	11.34	11.92	13.19	15.04
Pred. R^2	-0.3760	-1.4113	-0.5986	-6.3076	-0.3834	-1.2716	-2.5159	-51.8535
PRESS	6.64	11.64	64.11	35.27	9.45	15.52	24.02	361.14
Adeq. Prec.	0.8031	1.9629	2.5346	2.0922	1.0309	2.5830	1.9533	1.8540
	Appearance				Overall acceptability			
SD	0.9814	1.04	0.96	1.18	0.8671	0.9377	0.98	1.14
R^2	0.1496	0.2255	0.4914	0.5370	0.1332	0.1763	0.3080	0.4426
Mean	5.81	5.81	5.81	5.81	7.05	7.05	7.05	7.05
Adj. R^2	-0.0098	-0.1320	0.0336	-0.4663	-0.0293	-0.2039	-0.3148	-0.7650
C.V.	16.90	17.89	16.53	20.36	12.29	13.29	13.89	16.09
Pred. R^2	-0.2403	-0.7366	-0.6625	-276.5253	-0.2020	-0.9019	-1.2636	-199.0327
PRESS	22.48	31.47	30.13	5028.95	16.68	28.40	31.42	2776.22
Adeq. Prec.	3.6094	3.2862	3.5799	2.7795	3.8369	3.1694	2.5905	2.3246

SD = standard deviation, CV = coefficient of variation, R^2 = coefficient of determination, Adeq. Prec. = adequacy of precision, Adj. R^2 = adjusted coefficient of determination, Pred. R^2 = predicted coefficient of determination, PRESS = predicted residual sum of squares.

(B, C), OCT (B, C^2), and KER (AB, AC) as shown in Table 4. A, B, and C represent the MC, SR, and PT. From the results obtained it was noticed that SR and PT had the highest effect of the significant models. The "Lack of Fit F-values" for the HRY, BR, MRY, FBR, OCT, KER, WER, aroma, flavor, texture, appearance, and overall acceptability were 0.4993, 0.3820, 1.65, 0.2161, 0.2945, 2.14, 0.2869, 1.67, 0.2512, 0.2371, 1.14, and 0.5471 respectively (Table 4). Significant Lack of Fit F-value is not preferred because we want the model to fit. Lack of Fit F-values was not significant for responses considered. Adeq. Precision determines the ratio of signal to noise, and a value greater than 4 is desirable. The Adeq precision ratios for HRY, BR, MRY, FBR, OCT, KER, WER, aroma, flavor, texture, appearance, and overall acceptability were 0, 5.60, 10.23, 3.77, 5.96, 9.35, 4.90, 6.11, 0, 0, 3.58, and 0 respectively (Table 5). The values greater than 4 showed an adequate signal required for navigating within the design space. The R^2 values for HRY, BR, MRY, FBR, OCT, KER, WER, aroma, flavour, texture, appearance, and overall acceptability were 0, 0.31, 0.30, 0.73, 0.77, 0.6, 0.54, 0.41, 0, 0, 0.49, and 0 respectively (Table 5). This indicates that BR, MRY, aroma, KER, and appearance were poorly correlated below 0.5. For HRY, flavor, texture, and overall acceptability the overall mean was used so the R^2 value was not available as shown in Table 4. The linear terms showed the highest significance. The summary of the ANOVA indicates that the SR and PT had a significant effect on the MRY, OCT, and KER, whereas MC only had a significant effect on KER. The SR and PT were observed to have an equally significant effect on the various responses analyzed. Shittu and Ndirika (2012) reported that operational SR had the highest effect on percentage seed damage. The prediction models for BR, MRY were linear; FBR, OCT, WER, and Appearance were quadratic; KER and Aroma were 2-factorial interactions. Whereas for HRY, flavor, texture, and overall acceptability the overall mean was suggested due to negative adjusted and predicted R^2 value (Tables 4 and 5).

4. Conclusions

The research results showed that the processing parameters (moisture content, shaft speed, and polishing time) had a significant influence on cooking, some milling, and sensory properties of the polished rice. Increasing the moisture content (MC) and shaft speed of rotation (SR), increased the percentage of broken rice (BR), milled rice yield (MRY), optimum cooking time (OCT), kernel elongation ratio (KER), width expansion ratio (WER), appearance and rice aroma after cooking but had a fluctuating effect on fine broken rice (FBR), while increasing in MC and polishing time (PT) increased the BR, MRY, KER, and appearance and rice aroma after cooking but had a fluctuating effect on FBR, OCT, WER. Increasing SR versus PT increased BR, MRY, FBR, KER, WER, aroma, and appearance. The interactive effects of these processing variables had no significant effect on head rice yield, rice flavor after cooking, texture, and its overall acceptability by consumers. This research further showed that using a one-step milling machine, some of the milling (FBR, BR, MRY), cooking (OCT, KER, WER), and sensory properties (aroma and appearance) are affected by the processing parameters (MC, SR, and PT), and these results are useful for rice milling industries.

Declarations

Author contribution statement

Adeniyi T. Olayanju, Clinton E. Okonkwo, John O. Ojediran: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Syed Z. Hussain: Conceived and designed the experiments; Wrote the paper.

Ewhoritsemogha P. Dottie, Ayooluwa S. Ayoola: Performed the experiments; Wrote the paper.

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Data will be made available on request.

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The authors declare no conflict of interest.

Additional information

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