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Research Article

Optimizing parboiling conditions to improve grain quality and cooking properties of *Agric* and *Ofada* rice varieties

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Abstract Rice is one of the most important food crops in Nigeria. This study evaluated the effect of parboiling temperature and time on some quality parameters in two varieties of rice grains (*Agric* and *Ofada*). The bulk density, rate of breakage, grain dimensions, and minimum cooking properties of the rice varieties were investigated using standard methods. The results showed that, during milling, when the optimum parboiling temperature of *Agric* and *Ofada* rice grains is not attained or is exceeded, the grains are prone to more breakage due to the milling efficiency of the machine. Minimal grain breakage was observed at 135℃ for *Agric* rice and 150℃ for *Ofada* rice when parboiled for 25 min. The grain size ranged from 6.3-6.9 mm for whole rice, 3.2-4.2 mm for half grains, and 0.7-1.8 mm for fragments. In conclusion, *Agric* rice parboiled at 135℃ and *Ofada* rice parboiled at 150℃ for 25 min exhibited optimal quality, including lower breakage rates, higher whole grain yield, and favourable sensory characteristics.

Keywords *Agric* rice, *Ofada* rice, parboiling, grain breakage, grain dimensions, cooking quality

1. Introduction

Rice (*Oryza sativa*) is one of the most widely consumed staple crops globally, serving as a dietary foundation for over half the world's population (FAO, 2020). Ibukun (2008) reported that Nigeria produced about 2.3 million tons of rice and consumed about 5 million metric tons annually, leaving a deficit of 2.1 million metric tons. Locally milled rice in Nigeria is poor in quality and cannot compete with imported rice both in terms of price and quality (Adesina et al., 2017). In Nigeria, urban consumers have a greater preference for imported rice than locally produced rice. The latter was attributed to the poor cooking quality of local rice. To enhance the competitiveness of local rice with imported ones, it is necessary to improve the physical and cooking attributes of local rice grains (Bello et al., 2015; Meresa et al., 2020).

In principle, the traditional method of processing involves: 2-3 days soaking of rice paddy in water, to soften the kernel, followed by 5-10 min steaming of soaked paddy and sun drying. The process further involves the use of either a mortar and pestle to remove the husk or simple milling/dehulling machines for husk removal, followed by winnowing of grains. Although the local processing steps are simple, it is a tedious manual process and often leads to breakages of rice kernels into fragments and incomplete removal of husks. More so, processed grain has a short storage life, as the fat in the bran develops rancidity.

Variety is one of the main factors that have been identified to affect the quality and yield of paddy during milling. Different varieties of rice react differently to cracking in the grains due to their different genetic composition. The yield of rice after milling not only depends on the post-harvest handling, especially the drying conditions, but also on the variety of rice itself (Odoom, 2021).

Parboiling is defined as the hydrothermal processing of rice paddy prior to milling. The primary objective of parboiling is to enhance the grain quality of rice to optimize milling yield (Gbabo and Ndagi, 2014). Broken rice grain often reduces the market value of rice compared to whole grain price, well-parboiled rice often results in improved kernel strength, increased milling recovery, reduced nutrient loss and, improved storage life (World Bank, 2006).

Parboiling can be performed under different processing conditions. Differences in parboiling procedures often result in rice with varying physical qualities, thus affecting consumers' preferences. A survey report by Bello et al. (2015) on rice parboiling in Nigeria showed that 99% of the respondents still use the local parboiling method, whereas only 1% used the improved method in Kano State, Nigeria. Muchlisyiyah et al. (2023) reviewed the literature on the parboiling of rice under different conditions. Adekoyeni et al. (2018) recommended aerated drying of *Ofada* rice (A local rice variety) under shade for optimizing grain yield quality. There is a dearth of literature on the application of steam in the parboiling of the two Nigerian rice varieties (*Agric* and *Ofada*) of rice, hence this study. Optimizing the parboiling temperature of *Agric* and *Ofada* rice could further help in reducing the breakage of these rice grains. Such knowledge is expected to enhance the processing quality of these varieties. The objective of this study is to investigate the influence of parboiling at high temperatures on the physical (grain dimensions, rate of breakage, bulk density) and cooking properties of two rice varieties (*Agric* and *Ofada* rice grains) grown in Nigeria.

2. Materials and methods

2.1. Sample collection and preparation

Freshly harvested local paddy rice (*Oryza sativa)* called *Agric* rice and *Ofada* rice were obtained from a local market in Ile-Ife, Osun State, Nigeria. About 500 g of cleaned paddy rice were soaked in water at 70°C for 6 h to hydrate the kernels (Otegbayo et al., 2001). The soaked kernels were placed in 1 L of water (room temperature), then parboiled at three different temperatures (120, 135, and 150°C) and times (15, 20, and 25 min) using an electric pressure cooker (Bosch, Model No MES6817, 1050W, 6 L, Germany) following a 3 by 3 full-factorial experimental design. The samples were sun-dried (30±2°C) for 7 h to a moisture content range of 12-14% as recommended by Adekoyeni et al. (2018). The dried samples were dehulled using a laboratory dehuller.

2.2. Determination of physical properties

The physical properties measured for the grains include grain dimensions (length, thickness, and width), bulk density determination, and cooking properties (minimum cooking time and swelling ratio).

2.2.1. Grain dimensions

The grain thickness (T), length (L), and width (W) were determined using a digital Vernier calliper (0.1-100 mm A&D Company Limited, Tokyo, Japan). Following the method of Danbaba et al. (2012), ten whole grains of each rice variety were selected randomly. The dimensions (length and width) of each grain were estimated using a digital Vernier calliper (0.1-100 mm A&D Company Limited). While the grain shape in terms of length-to-width ratio was determined using the equation (Danbaba et al., 2012):

$$\text{Length to width ratio} = \frac{\text{Average grain length (mm)}}{\text{Average grain width (mm)}} \quad (1)$$

2.2.2. Thousand grain weight (TGW)

The mean weight of a 1,000 random sampling of well–developed, whole grains was weighed on an electronic balance (Danbaba et al., 2012).

2.2.3. Bulk density

The average bulk density was determined by filling a 10 mL glass cylinder with grains with no compaction of the seeds to a constant height. The volume of the cylinder was

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calculated using Equation (2) and the bulk density as shown in Equation (1) by Chavan et al. (2018), and it was repeated for ten replications.

$$P = \frac{W}{V} \quad (1) \quad \text{and} \quad V = \pi r^2 h \qquad (2)$$

Where ρ is bulk density (g/mL), W is the mass of the grain sample (g), V represents the volume of the grain sample (mL), r is the radius, and h is the height.

2.2.4. Broken rice grains

The grains were grouped into three categories: whole (5.4-6.9 mm), half (2.5-4.2 mm), and fragments (0.7-1.8 mm), and a vernier calliper was used to measure the length of the grains (See Fig. 1). The proportion of the weight of broken rice grains to the weight of the whole sample is stated as the percentage of rice breakage. The sound grains were separated from the broken rice with the aid of a rotary sieve. The grains were physically counted after separation and weighed to determine the number and weight of broken kernels present in each milled rice variety (Aghayeghazvini et al., 2009). Siebenmorgen et al. (2012) defined head rice yield (HRY) as the mass of head rice, expressed as a percentage of the original rough rice mass. Head rice yields can vary from 0 (all kernels are broken) to a theoretical maximum of approximately 70% (no kernels are broken).

2.3. Determination of cooking properties

2.3.1. Minimum cooking time (MCT)

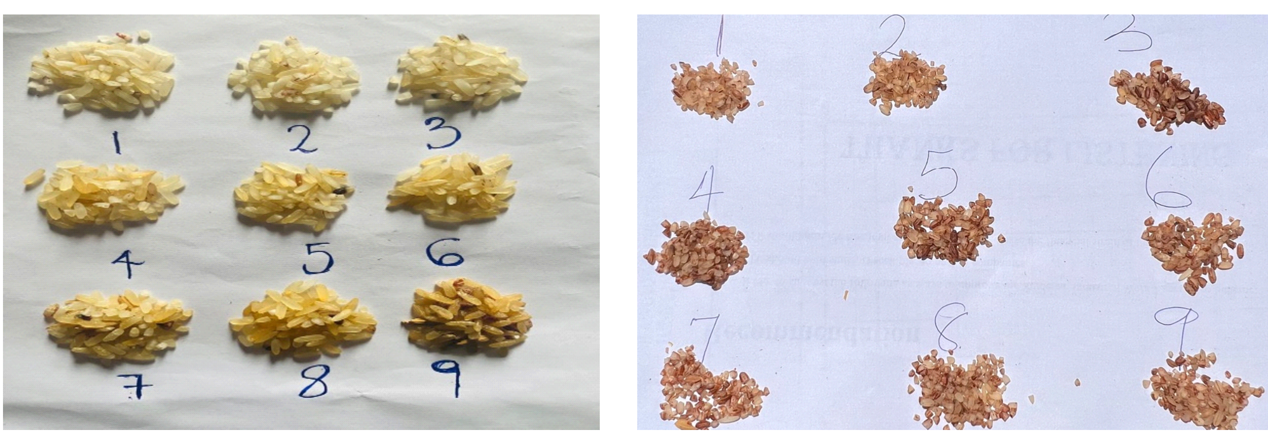
This test was carried out using the method of Singh et al. (2015). About 2 g of whole grain rice samples were placed in a test tube and cooked in 20 mL of distilled water in a boiling water bath. The cooking time was determined by removing a few kernels at different time intervals during cooking and pressing them between two glass plates until no white core was left.

2.3.2. Swelling ratio

About 8 g of the milled rice was placed inside a wire meshed cooking basket. The height of raw rice in the cooking basket was measured with a digital calliper (H_1). All samples were cooked for 15, 20, and 25 min. Towards the end of each cooking time, the cooking basket was removed and placed erect for 2 min to drain excess water. The height of cooked rice in the cooking basket was measured using a digital calliper (H_2). The determination in this study was conducted in triplicate using the formula of (Meresa et al., 2020).

$$\text{Swelling ratio} = \frac{H_2}{H_1} \qquad (3)$$

Where, H_1 = Height of raw rice (mm) and H_2 = Height of cooked rice (mm)



Agric rice

Ofada rice

Fig. 1. Milled samples of *Agric* and *Ofada* rices parboiled at different temperatures and times. Milled *Agric* & *Ofada* samples labelled 1, ($A\&O_{120/15}$); 2, ($A\&O_{120/20}$); 3, ($A\&O_{120/25}$), 4, ($A\&O_{135/15}$); 5, ($A\&O_{135/20}$); 6, ($A\&O_{135/25}$); 7, ($A\&O_{150/15}$); 8, ($A\&O_{150/20}$); 9, ($A\&O_{150/25}$).

2.4. Data analysis

An analysis of variance test was carried out using SPSS software (version 20.0). All data were analyzed using analysis of variance (ANOVA) in SPSS version 20.0. Means were compared using Duncan's multiple range test at $p<0.05$. Results are presented as mean±standard deviation (SD).

3. Results and discussion

3.1. Bulk density of two rice varieties (Agric and Ofada)

The results for bulk density are presented in Table 1. The results showed that as processing time and temperature increased, the bulk density reduced, although the reduction was not significant ($p>0.05$). Among the samples of each variety, samples processed at 120℃ for 15 min had the highest bulk density values, while samples processed at 150℃ for 25 min had the lowest values. In both varieties, the whole grains had higher bulk density values than the half grains and the fragments. Whole grains had a bulk density range of 1.06-1.24 g/mL, followed by half grains (0.86-1.08 g/mL), and fragments (0.80-0.99 g/mL) for the *Agric* variety. *Ofada* samples had bulk density values of (0.88-0.91 g/mL), (0.82-0.86 g/mL), and (0.81-0.84 g/mL) for the whole, half grains, and fragments, respectively. Generally, the bulk density of the *Ofada* variety was significantly lower than that of the *Agric* variety ($p<0.05$).

The reduced bulk density of broken grains may have resulted from reduced voids between the grains, suggesting that the smaller the grain size, the smaller the bulk density. Broken grains and fragments have been reported to feature

Table 1. Bulk density of milled *Agric* rice and *Ofada* rice

	Bulk density (g/mL)		
	Grain size		
Samples[1)]	Whole	Half broken	Fragment
$Agric_{120/15}$	1.24±0.01[2)NS3)]	1.08±0.01[NS]	0.99±0.01[NS]
$Agric_{120/20}$	1.21±0.01[NS]	1.05±0.01[NS]	0.97±0.01[NS]
$Agric_{120/25}$	1.20±0.01[NS]	1.04±0.01[NS]	0.95±0.01[NS]
$Agric_{135/15}$	1.19±0.01[NS]	1.00±0.01[NS]	0.89±0.01[NS]
$Agric_{135/20}$	1.18±0.01[NS]	0.98±0.01[NS]	0.86±0.01[NS]
$Agric_{135/25}$	1.16±0.01[NS]	0.95±0.01[NS]	0.85±0.01[NS]
$Agric_{150/15}$	1.15±0.01[NS]	0.92±0.01[NS]	0.83±0.01[NS]
$Agric_{150/20}$	1.12±0.01[NS]	0.89±0.01[NS]	0.82±0.01[NS]
$Agric_{150/25}$	1.06±0.01[NS]	0.86±0.01[NS]	0.80±0.01[NS]
$Ofada_{120/15}$	0.91±0.01[NS]	0.86±0.01[NS]	0.84±0.01[NS]
$Ofada_{120/20}$	0.90±0.01[NS]	0.85±0.01[NS]	0.84±0.01[NS]
$Ofada_{120/25}$	0.90±0.01[NS]	0.84±0.01[NS]	0.83±0.01[NS]
$Ofada_{135/15}$	0.89±0.01[NS]	0.84±0.01[NS]	0.83±0.01[NS]
$Ofada_{135/20}$	0.90±0.01[NS]	0.84±0.01[NS]	0.83±0.01[NS]
$Ofada_{135/25}$	0.89±0.01[NS]	0.83±0.01[NS]	0.83±0.01[NS]
$Ofada_{150/15}$	0.88±0.01[NS]	0.82±0.01[NS]	0.82±0.01[NS]
$Ofada_{150/20}$	0.89±0.01[NS]	0.82±0.01[NS]	0.82±0.01[NS]
$Ofada_{150/25}$	0.88±0.01[NS]	0.82±0.01[NS]	0.81±0.01[NS]

1)*Agric* & *Ofada* rices parboiled at different temperatures (℃)/mins.
2)Values are means±SD (n=3).
3)NS, not significant along the same column by Duncan's multiple range test ($p>0.05$).

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lower bulk densities than whole grains (Abd El-Sattar et al., 2016; El-Bana et al., 2010). Moreover, factors such as initial moisture content, variety of rice, temperature, and duration of parboiling and the specific methods of heating employed were reported to affect the bulk density of rice grains (Jiamyangyuen and Ooraikul, 2008). The influence of the parboiling temperature on rice grains, whether whole, broken, or fragmented, reflected a reduction in bulk density. As heating is applied and intensified either by longer duration or higher temperature, it promotes starch gelatinization within the rice grains, causing expansion and softening. Such changes in bulk density due to parboiling have practical implications for the storage, packaging, and transportation of rice.

3.2. Influence of processing on breakage of dehulled Agric and Ofada rice grains

Table 2 shows the average number of whole grains, half grains, and fragments of the processed paddy rice after milling/dehulling. At the three temperatures used, the percent of whole grains increases as parboiling time rises. For *Agric* samples processed at 120, 135, and 150℃, the percent whole grains for *Agric* samples ranged between 22-43%, 48.5-73%, and 51.5-63% respectively, while percent whole grains in *Ofada* samples ranged between 12.5-17.5%, 32.5-44.5%, and 23-42.5% respectively. In both varieties, parboiling at 135℃ for 25 min produced the highest proportion of whole grains (42.5-73%), whereas processing at 120℃ for 15 min gave the least whole grains. A similar study on breakage percentage

Table 2. Effect of processing on breakage of dehulled *Agric* and *Ofada* rice grains

Sample[1)]	Grain size								
	Whole			Half broken			Fragments		
	Counts (no)	Weight (g)	Percentage (%)	Counts (no)	Weight (g)	Percentage (%)	Counts (no)	Weight (g)	Percentage (%)
A_{Raw}	84±2	2							
$A_{120/15}$	21	0.4	22	72	0.85	43	107	0.71	35.5
$A_{120/20}$	32	0.7	34.5	51	0.61	31	106	0.7	35
$A_{120/25}$	42	0.9	43	56	0.69	35	63	0.45	22.5
$A_{135/15}$	47	1	48.2	45	0.54	27	66	0.49	24.5
$A_{135/20}$	64	1.4	68.1	30	0.48	24	23	0.16	8
$A_{135/25}$	69	1.5	73	18	0.37	19	28	0.18	9
$A_{150/15}$	48	1	51.5	62	0.77	39	26	0.19	9.5
$A_{150/20}$	54	1.2	59.5	48	0.62	31	28	0.19	9.5
$A_{150/25}$	58	1.3	63	40	0.51	26	23	0.16	8
O_{Raw}	77±2	2							
$O_{120/15}$	12	0.3	12.5	61	0.87	44	125	0.88	44
$O_{120/20}$	14	0.3	13	67	0.9	45	126	0.84	42
$O_{120/25}$	18	0.4	17.5	70	0.94	47	99	0.68	34
$O_{135/15}$	34	0.7	32.5	70	0.97	49	51	0.37	18.5
$O_{135/20}$	37	0.8	41.5	60	0.8	40	53	0.37	18.5
$O_{135/25}$	42	0.9	44.5	38	0.57	29	59	0.54	27
$O_{150/15}$	21	0.5	23	36	0.47	24	136	1.07	53.5
$O_{150/20}$	33	0.7	35.5	30	0.45	23	96	0.84	42
$O_{150/25}$	40	0.9	42.5	43	0.47	24	23	0.68	34

[1)]*Agric* & *Ofada* rices parboiled at different temperatures (℃)/mins.

recorded between 55-65% for parboiled *Ofada* rice and 18.6-26.1% for FARO 15 and OS 6 (Adekoyeni et al., 2018).

At 120℃, time did not have a significant ($p>0.05$) effect as there was just about a 5% difference in the whole grains between 15 and 25 mins. However, as time increased (from 15 to 25 min under 135 and 150℃), the difference was 12% and 9%, respectively. This result suggests a strong interaction between temperature and time. Whole grain percentage increased with temperature from 120℃ to 135℃. However, a further increase to 150℃ led to a reduction in whole grain recovery, indicating that 135℃ may be the optimal temperature for both rice varieties. These results suggest optimal processing at 135℃.

The percent broken grains (half or fragments) decreased with time, and the proportions ranged between 18.25-42.50% and 8.0 and 35.5% for half grains and fragments, respectively, in the *Agric* variety. Processing at 120℃ resulted in the highest percentage of fragments in both varieties. Fissured, immature, or chalky kernels are weak and may contribute to the production of broken grains during milling. Substantial forces are imparted on the kernels during milling to remove the rice bran, thus resulting in breakages and reduced milling yield (Siebenmorgen et al., 2012).

During parboiling, once the optimum parboiling temperature is not attained, there is a tendency for the whole grains to be subjected to breakage. The raw *Agric* samples (2 g), which were not subjected to any heating process (control), yielded 84±3 whole grains, and the *Ofada* variety had 77±4 whole grains. Ibukun (2008), reported that *Ofada* rice had more heat resistance compared to *Agric* grains.

Starch gelatinization and fissuring of the kernels influence the rigidity of parboiled rice (Muchlisyiyah et al., 2023). Gelatinization of starch has been reported to cause a homogenous and compact ultrastructure that results in the hardness of the rice grain. The degree of starch gelatinization and granule swelling is influenced by soaking and heating conditions. Some characteristics of rice starch, notably glass transition (Tg) and crystallinity, are modified by gelatinization (Muchlisyiyah et al., 2023). Adekoyeni et al. (2018) reported that adequately parboiled rice upon milling gave a higher HRY and was harder, while incomplete parboiling resulted in increased kernel breakage upon milling. The effect of cultivar and parboiling temperature was deduced as being responsible for the variation in HRY of rice.

Colour is one of the important parameters influencing the acceptability of rice as a food product. Fig. 1 shows the milled grains for the two varieties after parboiling under different conditions of grains. Although no quantitative measurement was done, the higher the temperature and the longer the processing time, the darker the colour of the grains. This result is similar to that of Taghinezhad et al. (2015), who reported that increasing the length of steaming time caused a significant increase ($p<0.05$) in the colour values of parboiled rice. Variation in the processing parameters of the soaking water (temperature and heating duration) influences the colour of parboiled brown rice changes depending on the colour of the milled rice, ranging from white to yellow (Bhattacharya and Subba Rao, 1966). Adesina et al. (2017), reported that the parboiling process turned the rice light yellow rather than white, probably due to the husk and bran layer moving toward the middle of the kernel. Steaming the grains in their husk causes nutrients, including fibre, to shift from the husk into the grain itself. Adekoyeni et al. (2018), reported a strong variation in colour among *Ofada* varieties. The *Ofada* rice is believed to be the Red *Ofada* variety, which is brown and has a very strong aroma. The uncooked form is reported to have an unappealing appearance, but it has a sweeter taste and smells better.

3.3. Thousand grain weight (TGW)

Table 3 shows the thousand-grain weight of the two varieties of rice studied. The values for *Agric* variety ranged between 21.2-22.8 g and 20.4-22.8 g for *Ofada* rice. There was no significant difference ($p>0.05$) in the values of the two varieties. The effect of parboiling temperature and time was not significant on the thousand-grain weight after processing. This suggests that the structural integrity of the rice kernels was maintained during parboiling, and any water absorption or loss was offset during the drying phase, leading to minimal changes in final kernel weight.

In the study by Danbaba et al. (2012), *Ofada* 10, *Ofada* 3, and 4 had a thousand-grain weight values ranging from 24.0 g to 31.0 g. the thousand kernel weight for the landraces varied from 25.65 g to 12.62 g and the maximum of 25.65 g for Rato Masino and the minimum 1,000 kernel weight was of Kalo Masino (12.62 g) (Pokhrel et al., 2020). Moisture content was reported to affect grain weight (Simonyan et al., 2007). The weight of grains in a holding bin of known volume during storage and handling can be estimated using

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Table 3. 1,000-grain weight of milled rice grains

Agric[1)]	Weight (g)[2)]	*Ofada*	Weight (g)
$A_{120/15}$	22.8±1.00[NS3)]	$O_{120/15}$	21.4±0.75[NS]
$A_{120/20}$	21.9±0.06[NS]	$O_{120/20}$	20.9±0.65[NS]
$A_{120/25}$	21.2±0.58[NS]	$O_{120/25}$	20.4±0.85[NS]
$A_{135/15}$	21.6±0.85[NS]	$O_{135/15}$	22.8±0.70[NS]
$A_{135/20}$	22.3±0.67[NS]	$O_{135/20}$	22.1±0.55[NS]
$A_{135/25}$	22.2±0.75[NS]	$O_{135/25}$	21.5±0.89[NS]
$A_{150/15}$	22.4±0.67[NS]	$O_{150/15}$	22.8±0.45[NS]
$A_{150/20}$	21.8±0.65[NS]	$O_{150/20}$	22.5±0.75[NS]
$A_{150/25}$	21.4±0.85[NS]	$O_{150/25}$	24.3±0.65[NS]

[1)] *Agric* & *Ofada* rices parboiled at different temperatures (℃)/mins.
[2)] Values are means±SD (n=3).
[3)] NS, not significant along the same column by Duncan's multiple range test (p>0.05).

the 1,000-grain weight value.

3.4. Influence of parboiling on the dimensions of milled whole grains

Data on the dimensions of the grains are shown in Table 4. The raw grains had 5.5 and 5.4 mm length, 1.3 and 2.6 mm width, and 0.8 and 1.8 mm thickness for *Agric* and *Ofada* varieties, respectively. These results suggest that in the raw form, both varieties are similar in length, while the *Ofada* grains are wider and thicker than the *Agric* grains. After parboiling, there was an enlargement in the dimensions of the whole grains. Whole *Agric* samples had 6.6-6.9 mm length, 1.8-2.0 mm width, and a thickness of 0.9-1.00 mm. This shows a 20-25.5% increase in length, 38.5-53.8% in width and 12.5-25% in thickness. After parboiling, the dimensions of whole *Ofada* samples, 5.7-6.3 mm, 2.6-2.9 mm, and 1.8-2.0 mm in length, width, and thickness, respectively, exhibited an increase of 5.5-16.7% in length, 0.0-11.5% in width, and 0.0-11.1% in thickness, respectively. The results of Otegbayo et al. (2001) showed that variety or cultivar had a greater effect on the size of rice more than the processing method employed.

The influence of time on grain dimensions was temperature-dependent. Parboiling *Agric* grains at 120 or 135℃, the dimensions of the whole grains increased between 15 and 20 mins of heating, but with further heat treatment, the dimensions either remained unchanged or reduced slightly. No significant difference was observed in thickness (p>0.05) of *Ofada* grains parboiled for 15-20 min, as determined by one- way ANOVA. Slight expansions were observed at 25 min of parboiling.

Uniformity in shape and size of rice kernels is important quality characteristic in the industry. The average length (mm) of milled rice has been classified into four categories depending on the type of grains: short (≤5.50 mm), medium (5.51-6.60 mm), long (6.61-7.50 mm), and extra-long (>7.50 mm) (Ahuja et al., 1995). The results in Table 3 showed that the length of parboiled *Agric* rice grains is in the long category, and the *Ofada* grains are in the medium category. The results are similar in trend to those reported in other studies (Abd ElSattar et al., 2016; Gewaily et al., 2019; Otegbayo et al., 2001). However, the ratio of the length to the width of the grain determines the shape of rice grains (Ahuja et al., 1995). The grain thickness was the same with no significant difference (p>0.05). There was not much variation in the thickness after parboiling. The original *Ofada* rice was described as short-grain, robust rice with brown stripes (Adekoyeni et al., 2018). The red kernel in unpolished short-grain *Ofada* rice is not common in any other rice varieties in Nigeria.

3.5. Cooking properties of milled rice

Results given in Table 5 show the cooking properties of *Agric* and *Ofada* rice in terms of minimum cooking time and swelling capacity. *Agric* and *Ofada* rice samples parboiled at 120 and 135℃ had a cooking time of 30 min, which is

Table 4. Dimensions of milled *Agric* and *Ofada* grains parboiled at different conditions

Sample[1)]	Grain size[2)]								
	Whole grains			Half broken			Fragments		
	Length	Width	Thickness	Length	Width	Thickness	Length	Width	Thickness
	(mm)			(mm)			(mm)		
A_{Raw}	5.5±0.01[NS]	1.3±0.01[NS]	0.8±0.01[NS]						
$A_{120/15}$	6.6±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	3.2±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	1.0±0.01[NS]	0.5±0.01[NS]	0.5±0.01[NS]
$A_{120/20}$	6.8±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	3.4±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	1.1±0.01[NS]	0.4±0.01[NS]	0.4±0.01[NS]
$A_{120/25}$	6.7±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	3.4±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	1.0±0.01[NS]	0.8±0.01[NS]	0.8±0.01[NS]
$A_{135/15}$	6.8±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	3.6±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	0.9±0.01[NS]	0.5±0.01[NS]	0.5±0.01[NS]
$A_{135/20}$	6.9±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	3.4±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	0.7±0.01[NS]	0.5±0.01[NS]	0.5±0.01[NS]
$A_{135/25}$	6.9±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	4.0±0.02[NS]	2.0±0.01[NS]	1.0±0.01[NS]	0.9±0.01[NS]	0.6±0.01[NS]	0.6±0.01[NS]
$A_{150/15}$	6.9±0.02[NS]	2.0±0.01[NS]	0.9±0.01[NS]	4.2±0.02[NS]	2.0±0.01[NS]	0.9±0.01[NS]	0.8±0.01[NS]	0.9±0.01[NS]	0.9±0.01[NS]
$A_{150/20}$	6.3±0.02[NS]	1.8±0.01[NS]	0.9±0.01[NS]	3.4±0.02[NS]	1.8±0.01[NS]	0.9±0.01[NS]	1.1±0.01[NS]	1.1±0.01[NS]	1.1±0.01[NS]
$A_{150/25}$	6.3±0.02[NS]	1.8±0.01[NS]	1.0±0.01[NS]	3.5±0.02[NS]	1.8±0.01[NS]	1.0±0.01[NS]	1.0±0.01[NS]	1.0±0.01[NS]	1.0±0.01[NS]
O_{Raw}	5.4±0.01[NS]	2.6±0.01[NS]	1.8±0.01[NS]						
$O_{120/15}$	5.9±0.02[NS]	2.8±0.01[NS]	2.0±0.01[NS]	2.9±0.02[NS]	2.8±0.01[NS]	2.0±0.01[NS]	1.4±0.01[NS]	1.2±0.01[NS]	1.0±0.01[NS]
$O_{120/20}$	5.8±0.02[NS]	2.6±0.01[NS]	2.0±0.01[NS]	2.7±0.02[NS]	2.6±0.01[NS]	2.0±0.01[NS]	1.3±0.01[NS]	1.0±0.01[NS]	0.9±0.01[NS]
$O_{120/25}$	6.0±0.02[NS]	2.7±0.01[NS]	2.0±0.01[NS]	2.9±0.02[NS]	2.7±0.01[NS]	2.0±0.01[NS]	1.5±0.01[NS]	1.1±0.01[NS]	0.9±0.01[NS]
$O_{135/15}$	6.0±0.02[NS]	2.8±0.01[NS]	2.0±0.01[NS]	2.8±0.02[NS]	2.8±0.01[NS]	2.0±0.01[NS]	1.6±0.01[NS]	1.2±0.01[NS]	1.0±0.01[NS]
$O_{135/20}$	6.0±0.02[NS]	2.7±0.01[NS]	2.0±0.01[NS]	2.8±0.02[NS]	2.7±0.01[NS]	2.0±0.01[NS]	1.3±0.01[NS]	0.9±0.01[NS]	0.8±0.01[NS]
$O_{135/25}$	6.3±0.02[NS]	2.9±0.01[NS]	2.0±0.01[NS]	2.9±0.02[NS]	2.9±0.01[NS]	2.0±0.01[NS]	1.8±0.01[NS]	0.9±0.01[NS]	0.7±0.01[NS]
$O_{150/15}$	5.7±0.02[NS]	2.7±0.01[NS]	2.0±0.01[NS]	2.7±0.02[NS]	2.7±0.01[NS]	2.0±0.01[NS]	1.4±0.01[NS]	1.2±0.01[NS]	1.0±0.01[NS]
$O_{150/20}$	5.7±0.02[NS]	2.8±0.01[NS]	2.0±0.01[NS]	2.5±0.02[NS]	2.8±0.01[NS]	2.0±0.01[NS]	1.3±0.01[NS]	0.9±0.01[NS]	0.8±0.01[NS]
$O_{150/25}$	6.0±0.02[NS]	2.8±0.01[NS]	2.0±0.01[NS]	2.6±0.02[NS]	2.8±0.01[NS]	2.0±0.01[NS]	1.5±0.01[NS]	1.2±0.01[NS]	1.0±0.01[NS]

1)*Agric* & *Ofada* rices parboiled at different temperatures (℃)/mins.
2)Values are means±SD (n=3).
3)NS, not significant along the same column by Duncan's multiple range test (p>0.05).

higher than for samples parboiled at 150℃ (20-25 min).

The time needed for the opaque central portion of the rice grain to completely disappear during cooking is referred to as the minimum cooking time (Itagi and Singh, 2015). The obtained results are similar to those reported in some earlier studies (Abd El-Sattar et al., 2016; Chavan et al., 2018; Gewaily et al., 2019; Zohoun et al., 2018). The longer cooking time observed between 120 and 135℃ may be attributed to reduced hydration rate during cooking for the samples compared to at 150℃. Muchlisyiyah et al. (2023) reported that parboiled rice takes a little longer to cook. The authors reported that white rice took about 15-20 min, while parboiled rice took about 25 min, which was still less than the 45-50 min needed for brown rice. Gelatinization occurs during heating in water and continues until the rice grains are fully cooked. Gelatinization temperature influences cooking time. Rice with a low gelatinization temperature requires a shorter cooking time than rice with a high gelatinization temperature (Juliano and Perez, 1983).

With exposure to longer heat, the grains absorb water and cause the rice to have a softer texture, resulting in swollen starch granules (Syafutri et al., 2016).

The swelling ratio of *Agric* rice ranged from 4.16-1.94 and 4.0-2.02 for *Ofada* rice (Table 5). The longer the cooking

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Table 5. Cooking properties of *Agric* rice and *Ofada* rice grains

Samples[1)]	Minimum cooking time (mins)	Water uptake ratio	Swelling ratio
$A_{120/15}$	30	4.02	4.16
$A_{120/20}$	30	4.11	3.96
$A_{120/25}$	30	3.51	3.50
$A_{135/15}$	30	3.18	3.25
$A_{135/20}$	30	3.11	2.88
$A_{135/25}$	30	3.04	2.72
$A_{150/15}$	25	2.99	2.29
$A_{150/20}$	20	2.47	2.08
$A_{150/25}$	20	2.38	1.94
$O_{120/15}$	30	3.95	4.00
$O_{120/20}$	30	3.63	4.10
$O_{120/25}$	30	3.47	3.08
$O_{135/15}$	30	3.20	3.02
$O_{135/20}$	30	3.07	3.00
$O_{135/25}$	30	2.98	2.74
$O_{150/15}$	25	3.50	2.87
$O_{150/20}$	20	2.56	2.36
$O_{150/25}$	20	2.24	2.02

[1)]*Agric* & *Ofada* rices parboiled at different temperatures (℃)/mins.

time, the lower the swelling ratio. Also, the swelling ratio was reduced at higher temperatures. The swelling ratio was significantly ($p<0.05$) influenced by temperature. The influence of variety on the swelling ratio of the grains was not significant ($p>0.05$). Parboiling time and amylose content of the grains influence the water absorption capacities of the rice varieties, which is believed to influence the expansion ratio of rice (Adekoyeni et al., 2018).

The water uptake ratio followed the same trend as the swelling ratio. The water uptake ratio ranged from 4.02-2.38 for *Agric* rice and 3.95-2.24 for *Ofada* rice. These findings suggest that while high-temperature parboiling (150℃) improves cooking time, it may compromise swelling capacity, which is often associated with textural appeal.

A significant difference was observed in the water uptake ratio ($p<0.01$) among the landraces (Pokhrel et al., 2020). A variation in the water uptake ratio (3.91 to 7.96) was observed among the varieties (7.96±0.037), (7.52±0.335), and (3.91±0.032) for Jetho Budo, Biramful and Rato Anadi grains, respectively. Water uptake by rice was reported to be a function of the surface area, which is influenced by the size and shape of the grains (Bhattaacharya and Sowbhagya, 1971). At a given cooking time, large and round varieties absorb less water than the small and slender varieties.

3.6. Regression relationships between parboiling conditions and some quality parameters of Agric and Ofada rice varieties

To better understand the influence of parboiling time and temperature on quality attributes of rice, regression models were developed for various physical and cooking parameters. The physical parameters -bulk density, breakage characteristics (count, weight, % breakage), dimensions (width, length, and thickness) and cooking properties of two rice varieties using different parboiling conditions are best described by the quadratic equation (see Table S1). Swelling capacity data was subjected to Linear, Logarithmic, Polynomial, Exponential, and Power Equations. The constant values and coefficient values for the different equations are presented in Tables S2-S6. The collated R^2 coefficient values for the different relationships (equations 4-8) establishing the relationship between the swelling capacity of *Agric* rice and *Ofada* rice and the processing conditions used are seen in Table S7.

Linear equation; $y = ax + b$ (4)

Logarithmic equation; $y = aln(x) + b$ (5)

Polynomial equation; $y = ax^2 + bx + c$ (6)

Exponential equation; $y = ae^{bx}$ (7)

Power equation; $y = ax^b$ (8)

From Table S7, the R^2 values for both varieties ranged between 0.8022 and 0.999. For the linear equation, the R^2 values ranged between 0.8622-0.9909, 0.8816-0.9922 for logarithmic, 0.8022-0.9828 for exponential equation, 0.9096-0.9990 for polynomial equation and 0.9229-0.9983 for power equation. This result indicates that any of the above equations can be used to predict the relationship between the swelling capacity of the rice and the parboiling conditions. For both rice varieties (*Agric* and *Ofada* rice), the highest R^2 values were obtained using the polynomial equation. The R^2 values of most of the samples were higher at 20-25 mins of parboiling. This suggests that swelling capacity is best predicted using second-order polynomial models under varying parboiling conditions. Although polynomial regression provided the best fit, overfitting may be a concern due to the limited sample points per treatment condition.

4. Conclusions

The effects of parboiling using steam on some cooking and physical qualities of two rice varieties, *Agric* and *Ofada,* were studied. As processing time and temperature increased, the bulk density of the grains reduced, and the whole grains had higher bulk density values than the broken grains (half and fragments). An increase in parboiling time, caused the percentage of whole grains to increase. For both varieties, parboiling at 135℃ for 25 min produced the highest proportion of whole grains. The longer the cooking time, the lower the swelling ratio. For both rice varieties (*Agric* and *Ofada* rice), the polynomial equation had the highest overall R^2 values, while the quadratic equation best described the relationship between physical parameters and the parboiling conditions.

Supplementary materials

Supplementary materials are only available online from: https://doi.org/10.11002/fsp.2025.32.4.613.

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Conflict of interests

The authors declare no potential conflicts of interest.

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Ethics approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

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Supplementary materials

Table S1. Best-fit-models' parameters and descriptive statistics of bulk density, breakage characteristics and cooking properties of two rice varieties using different parboiling temperature.

Parameters	Best-fit model	R^2	Mean	Range	STD	Model equation
Agric						
Bulk density	Quadratic	1	1.17	1.11 - 1.22	0.05	$y = -6E\text{-}05x^2 + 0.0124x + 0.5767$
Breakage characteristics						
Count	Quadratic	1	48.33	31.67 - 60	14.81	$y = -0.0778x^2 + 21.722x - 1455$
Weight	Quadratic	1	1.04	0.66 - 1.26	0.33	$y = -0.0015x^2 + 0.4253x - 28.617$
% Breakage	Quadratic	1	51.44	33.17 - 63.17	16.04	$y = -0.0781x^2 + 21.928x - 1472.8$
Dimension						
Length		0.9891	6.69	6.60 -6.87	0.18	$y = -0.0012x^2 + 0.3133x - 13.833$
Width		0.9858	1.96	1.87 - 2.00	0.08	$y = -0.0003x^2 + 0.0756x - 2.8$
Thickness		0.9347	0.98	0.93 - 1.00	0.04	$y = -0.0001x^2 + 0.0378x - 1.4$
Cooking properties						
Minimum cooking time	Quadratic	0.9497	27.22	21.67 - 30.00	4.81	$y = -0.0185x^2 + 4.7222x - 270$
Water uptake ratio	Exponential	0.9955	3.20	2.61 - 3.88	0.64	$y = 18.705e^{-0.013x}$
Swelling ratio	Linear	0.9996	2.93	1.96 - 3.87	0.96	$y = -0.0637x + 11.524$
Ofada						
Bulk density	Linear	1	0.89	0.88 - 0.90	0.01	$y = -0.0007x + 0.9833$
Breakage characteristics						
Count	Quadratic	0.8509	31.22	14.67 - 41.33	14.45	$y = -0.043x^2 + 12.489x - 865.33$
Weight	Quadratic	0.9138	0.67	0.29 - 0.92	0.33	$y = -0.0008x^2 + 0.2428x - 17$
Percentage	Quadratic	0.9125	33.22	14.33 - 45.83	16.66	$y = -0.0419x^2 + 12.35x - 865$
Dimension						
Length	Quadratic	0.7272	5.93	5.80 - 6.10	0.15	$y = -0.0011x^2 + 0.2967x - 13.7$
Width	Quadratic	0.8819	2.76	2.70 - 2.80	0.05	$y = -0.0003x^2 + 0.0822x - 2.9$
Thickness			2.00		0.00	
Cooking properties						
Minimum cooking time	Quadratic	0.9497	27.22	21.67 - 30.00	4.81	$y = -0.0185x^2 + 4.7222x - 270$
Water uptake ratio	Power	0.9961	3.19	2.77 - 3.68	0.46	$y = 1722.2x^{-1.285}$
Swelling ratio	Linear	0.9456	3.10	2.65 - 3.73	0.56	$y = -0.0359x + 7.9439$

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Table S2. **Regression relationship between the swelling capacity of *Agric* rice and *Ofada* rice at different processing conditions using linear equation**

Samples	Linear equation	R^2 values
A120/15	a=0.0757, b=2.106	0.8622
O120/15	a=0.4231, b=1.744	0.9194
A120/20	a=0.0738, b=1.6107	0.9538
O120/20	a=0.701, b=2.1847	0.9429
A120/25	a=0.063, b=1.622	0.9841
O120/25	a=0.0541, b=1.558	0.9512
A135/15	a=0.0579, b=1.6627	0.9366
O135/15	a=0.2429, b=1.6767	0.9611
A135/20	a=0.0426, b=1.47	0.9909
O135/20	a=0.0504, b=1.5847	0.9732
A135/25	a=0.0501, b=1.3707	0.9782
O135/25	a=0.049, b=1.3153	0.9861
A150/15	a=0.045, b=1.148	0.9724
O150/15	a=0.0617, b=1.986	0.9542
A150/20	a=0.0283, b=1.174	0.9016
O150/20	a=0.3284, b=1.696	0.9976
A150/25	a=0.038, b=1.0667	0.9453
O150/25	a=0.0413, b=1.258	0.9887

Table S3. **Regression relationship between the swelling capacity of *Agric* rice and *Ofada* rice at different processing conditions using logarithmic equation**

Samples	Logarithmic equation	R^2 values
A120/15	a=1.1367, b=0.3542	0.9766
O120/15	a=1.2385, b=1.8669	0.9881
A120/20	a=1.015, b=0.1551	0.9061
O120/20	a=1.0153, b=0.6644	0.9921
A120/25	a=0.8793, b=0.3456	0.9611
O120/25	a=0.7724, b=0.4148	0.9725
A135/15	a=0.8417, b=0.3989	0.9918
O135/15	a=0.6882, b=1.7721	0.9681
A135/20	a=0.5856, b=0.6305	0.9408
O135/20	a=0.7171, b=0.5263	0.9885
A135/25	a=0.698, b=0.3578	0.9545
O135/25	a=0.6821, b=0.3276	0.9578
A150/15	a=0.6109, b=0.2818	0.9005
O150/15	a=0.8875, b=0.6634	0.9922
A150/20	a=0.4038, b=0.5774	0.9182
O150/20	a=0.4434, b=1.0202	0.9149
A150/25	a=0.539, b=0.2732	0.9544
O150/25	a=0.55, b=0.4918	0.8816

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Table S4. Regression relationship between the swelling capacity of *Agric* rice and *Ofada* rice at different processing conditions using polynomial equation

Samples	Polynomial equation	R^2 values
A120/15	a=0.038, b=0.2077, c=1.226	0.9764
O120/15	a=0.0846, b=1.0156, c=0.954	0.9979
A120/20	a=0.00004, b=0.0725, c=1.619	0.9538
O120/20	a=0.0023, b=0.1521, c=1.638	0.999
A120/25	a=0.0007, b=0.087, c=1.462	0.9903
O120/25	a=0.0014, b=0.1036, c=1.228	0.9858
A135/15	a=0.002, b=0.1287, c=1.191	0.9974
O135/15	a=0.0291, b=0.4466, c=1.405	0.9905
A135/20	a=0.0001, b=0.0471, c=1.44	0.9914
O135/20	a=0.0011, b=0.0904, c=1.318	0.9999
A135/25	a=0.0003, b=0.0608, c=1.299	0.9801
O135/25	a=0.0005, b=0.066, c=1.202	0.9912
A150/15	a=0.0004, b=0.0322, c=1.233	0.9758
O150/15	a=0.0016, b=0.1172, c=1.616	0.9879
A150/20	a=0.0004, b=0.0411, c=1.089	0.9096
O150/20	a=0.0002, b=0.0275, c=1.731	0.9987
A150/25	a=0.001, b=0.0727, c=0.835	0.9798
O150/25	a=0.0005, b=0.0225, c=1.383	0.9976

Table S5. **Regression relationship between the swelling capacity of *Agric* rice and *Ofada* rice at different processing conditions using exponential equation**

Samples	Exponential equation	R^2 values
A120/15	a=2.1844, b=0.0244	0.8022
O120/15	a=1.8849, b=0.1443	0.8543
A120/20	a=1.7877, b=0.0262	0.9475
O120/20	a=2.2883, b=0.0218	0.901
A120/25	a=1.7515, b=0.024	0.9635
O120/25	a=1.6488, b=0.0028	0.915
A135/15	a=1.7498, b=0.0231	0.8906
O135/15	a=1.7542, b=0.1	0.9313
A135/20	a=1.5501, b=0.0196	0.9828
O135/20	a=1.6683, b=0.0214	0.9426
A135/25	a=1.471, b=0.0231	0.965
O135/25	a=1.4152, b=0.0234	0.9669
A150/15	a=1.2533, b=0.0236	0.9759
O150/15	a=2.0789, b=0.0213	0.9218
A150/20	a=1.2135, b=0.0175	0.8884
O150/20	a=1.7471, b=0.0145	0.9983
A150/25	a=1.1331, b=0.0231	0.9081
O150/25	a=1.3514, b=0.0209	0.9972

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Table S6. **Regression relationship between the swelling capacity of *Agric* rice and *Ofada* rice at different processing conditions using power equation**

Samples	Power equation	R^2 values
A120/15	a=1.2143, b=0.3747	0.9459
O120/15	a=1.9428, b=0.4329	0.9743
A120/20	a=1.0362, b=0.371	0.9373
O120/20	a=1.4032, b=0.3216	0.991
A120/25	a=1.0539, b=0.3433	0.9841
O120/25	a=1.0022, b=0.3313	0.981
A135/15	a=1.0372, b=0.3428	0.9878
O13515	a=1.8155, b=0.2878	0.9812
A135/20	a=1.0386, b=0.2747	0.9674
O135/20	a=1.0473, b=0.3103	0.9983
A135/25	a=0.9009, b=0.3304	0.975
O135/25	a=0.8663, b=0.3325	0.9819
A150/15	a=0.7765, b=0.30	0.9362
O150/15	a=1.2943, b=0.3123	0.9933
A150/20	a=0.8261, b=0.2556	0.9229
O150/20	a=1.3153, b=0.1988	0.9419
A150/25	a=0.6899, b=0.3327	9682
O150/25	a=0.9037, b=0.2839	0.9246

Table S7. Regression coefficient (R^2 values) for different Equations for the swelling capacity of *Agric* rice and *Ofada* rice at different processing conditions

Sample	Linear	Logarithmic	Polynomial	Exponential	Power
A120/15	0.8622	0.9766	0.9764	0.8022	0.9459
O120/15	0.9194	0.9881	0.9979	0.8543	0.9743
A120/20	0.9538	0.9061	0.9538	0.9475	0.9373
O120/20	0.9429	0.9921	0.999	0.901	0.991
A120/25	0.9841	0.9611	0.9903	0.9635	0.9841
O120/25	0.9512	0.9725	0.9858	0.915	0.981
A135/15	0.9366	0.9918	0.9974	0.8906	0.9878
O135/15	0.9611	0.9681	0.9905	0.9313	0.9812
A135/20	0.9909	0.9408	0.9914	0.9828	0.9674
O135/20	0.9732	0.9885	0.9999	0.9426	0.9983
A135/25	0.9782	0.9545	0.9801	0.965	0.975
O135/25	0.9861	0.9578	0.9912	0.9669	0.9819
A150/15	0. 9724	0.9005	0.9758	0.9759	0.9362
O150/15	0. 9542	0.9922	0.9879	0.9218	0.9933
A150/20	0.9016	0.9182	0.9096	0.8884	0.9229
O150/20	0.9976	0.9149	0.9987	0.9983	0.9419
A150/25	0.9453	0.9544	0.9798	0.9081	0.9682
O150/25	0.9887	0.8816	0.9976	0.9972	0.9246

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