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# Water Absorption Behavior of Milled Parboiled Rice in Relationship with Variety and Some Basic Thermodynamic Properties of Steam

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## *Abstract*

*The effect of variety and some basic thermodynamic properties of steam which include pressure and specific volume of steam on water absorption capacity of parboiled rice was studied. Four rice varieties, Faro 21, Faro 27, Faro 29 and Faro 35 were used for the experiment. An insulated electric paddy parboiler comprising a boiler and steamer was used to pre-treat the rice under established recommended conditions. The samples were then dried, milled and analyzed. The results showed that the rice treated with the first steam pressure of 1.0 x $10^4$ N/$m^2$, 1.148 $m^3$/kg and 1.576 $m^3$/kg levels of specific volume of steam absorbed more water cumulatively while the level of steam pressure of 5.5 x $10^4$ N/$m^2$, 1.290 $m^3$/kg and 1.433 $m^3$/kg levels of specific volume of steam recorded the least values. Among the rice varieties, Faro 29 was found to have 163.2 ml and 71.1 ml water absorption capacity at the highest and lowest cooking duration of 40 mins and 10 mins respectively. A regression equation which predicts cumulative water absorption capacity of rice at varying steam pressures and specific volumes of steam were also developed.*

***Keywords:*** *Water absorption capacity, rice variety, specific volume of steam, Steam pressure.*

## Introduction

Rice is the sixth major crop in cultivable area after sorghum, millet, cowpea and yam in Nigeria (Dauda and Adgidzi 2003). It is well known for its hygroscopic behaviour. However, it has been observed that the degree of swelling varies with varieties, raw and parboiled rice and processing methods (Juliano 1985). The potential of Nigeria in Rice production in terms of availability of land, human resources and weather is so enormous but the actual rice production level of the nation is so low that the country imports rice valued $600-700 million annually (Gbabo 2006). In Nigeria, parboiling of paddy before milling is widely practiced (Dauda and Agidi 2005).

Several investigations on how varietal difference affects the water absorption capacities of rice have been carried out. The physiochemical properties of the grain such as amylose content (Williams *et al*. 1958; Webb 1975; and Juliano 1979), amylographic gelatinization and paste viscosity characteristics (Hallick and Kelly 1959), protein content (AACC 1962), parboiling and canning stability (Webb and Adams 1970) greatly affect the water absorption capacities of the rice grain. However, among these quality indicators, amylose content has been found to be the single most important characteristics for predicting rice cooking (water uptake) behaviour (Sanjiva *et al*. 1952; Williams *et al*. 1958; Hallick and Keneastor 1959; Webb 1975; and Juliano 1979).

Juliano (1985) also carried out a study on the water uptake behaviour of raw and parboiled rice and found out that parboiled rice

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has lower water absorption capacity than raw rice thus retains better shape, fluffier, less sticky, more consistent and loses less solids during cooking.

Processing condition such as mode and degree of soaking of paddy influences water uptake capacity of the rice grain. In continuation of a previous work (Igbeka *et al*. 2008), this study investigates the effect of steam pressure, specific volume of steam and rice variety on the water absorption behavior on milled parboiled rice.

## Materials and Method

### Research Materials

Four cleaned paddy varieties: Faro 21, Faro 27, Faro 29 and Faro 35, were collected from the National Cereals Research Institute, Badeggi. A total of 192 kg of paddy for 64 treatments of 3 replications each were obtained. They represent the conventionally known grain sizes (short, medium and long) grown by Nigerian farmers. The paddy samples were shade dried to 13% moisture content (w.b.) before parboiling.

### Material Preparation

The materials were prepared for the experiments by soaking the paddy samples in water heated to 70$^{o}$C with the boiler under the same condition for 6 hrs in closed plastic containers. Closed plastic containers were used to minimize heat loss across the walls of the container.

### Experimental Procedure

An Electric Rice Parboiler was designed and fabricated to carry out the 3 experiments.

***Effect of pressure of steam on water absorption capacity of parboiled rice:*** Each of the soaked paddy samples was put into the steamer of the parboiler. The electric heating system of the boiler was then switched on after introducing water to the boiler to the level previously marked for the corresponding specific volume of steam and was left to boil. The pressure of the steam was then adjusted with the aid of a pressure relief valve to 1.0 x $10^4$ N/m$^2$ level. When a constant gauge pressure indicated by the bourdon pressure gauge attached to the steamer was attained, the steam passage valve of the steam conveying pipe that connects the boiler and the steamer was opened for steam to pass to parboil the rice in the steamer for 35 min. This procedure was repeated for the remaining three levels of pressure for each variety of paddy and specific volume of steam.

***Effect of specific volume of steam on water absorption capacity of parboiled rice:*** In this experiment, various levels of steam were used in parboiling the rice samples at constant steam pressures and rice varieties. This was done by evaporating water at different levels in the boiler with the aid of the electric heating system before passing the steam to the steamer containing the rice samples for 35 min.

***Effect of rice variety on water absorption capacity of parboiled rice:*** This experiment was performed by passing steam to parboil a particular paddy variety using constant level of steam pressure and specific volume of steam at a time. The experiment was repeated for all the remaining 3 paddy varieties.

***Drying:*** The 192 Kg steamed samples of paddy from the 3 experiments were thinly spread on a clean concrete floor in the shade in order to ensure gradual drying of individual paddy. Thin layer shade drying was preferred to open sun drying because stress gradients in the dried kernels which result in high breakage during milling are usually associated with sun drying (Juliano 1985). Also, shade drying ensures even tempering of the rice kernel resulting in less broken grain when milled. The samples were dried to 13% M.C. (w.b.).

***Milling:*** The dried samples of paddy were milled separately in a No. 45 Universal huller. The huller was always adjusted to the same degree of pressure for both dehusking and polishing operations for each sample of rice. The huller was properly cleaned to ensure no residue is left behind after each milling operation.

**Determination of Water Absorption Capacity of Rice**

350 ml of water was heated at 100°C in 650 ml capacity graduated cylinder. 25 grms of each of the samples was lowered into the cylinder and covered. They were cooked on a rectangular hot plate, HPS-460 for periods of 10 mins, 20 mins, 30 mins and 40 mins. The decrease in volume of water which is the amount of water absorbed indicates the swelling or water absorption capacity of the samples and was recorded (Batcher *et al.* 1986; Halick and Kelly 1992).

## Results and Discussion

Table 1 shows the cumulative water absorption pattern of rice under the various treatments.

The cumulative water absorption capacity of rice was higher for the lower levels of steam pressures for almost all the specific volume of steam and rice varieties at the initial cooking durations of 10-30 min. This trend reversed at 40 min cooking duration as shown in the table.

Table 1. Average cumulative water absorbed at time intervals of 10 mins, 20 mins, 30 mins and 40 mins for various combinations of pressures of steam, specific volume of steam in boiler and rice varieties.

| Average pressure in steamer ($x10^4 N/m^2$) | Specific volume of steam in boiler ($m^3/kg$) | Cumulative water absorbed (ml) Rice variety: Faro 21 | | | |
|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 |
| 1.0 | 1.148 | 122.6 | 132.5 | 135.3 | 137.3 |
| | 1.29 | 92.7 | 114.3 | 130.6 | 139.4 |
| | 1.433 | 115.4 | 120.0 | 125.1 | 130.2 |
| | 1.576 | 126.6 | 130.1 | 134.0 | 135.9 |
| 2.5 | 1.148 | 124.7 | 130.3 | 136.0 | 137.0 |
| | 1.29 | 90.2 | 104.6 | 131.4 | 140.2 |
| | 1.433 | 100.4 | 128.0 | 130.2 | 139.6 |
| | 1.576 | 125.3 | 128.6 | 133.6 | 139.8 |
| 4.0 | 1.148 | 120.3 | 128.0 | 135.7 | 139.6 |
| | 1.29 | 78.0 | 92.4 | 125.4 | 136.2 |
| | 1.433 | 79.5 | 125.0 | 128.9 | 140.0 |
| | 1.576 | 120.0 | 126.7 | 130.2 | 140.61 |
| 5.5 | 1.148 | 85.1 | 110.6 | 130.2 | 133.7 |
| | 1.29 | 47.8 | 88.0 | 120.9 | 130.2 |
| | 1.433 | 54.3 | 97.7 | 148.0 | 148.0 |
| | 1.576 | 78.6 | 84.3 | 91.5 | 103.8 |

| Average pressure in steamer ($x10^4 N/m^2$) | Specific volume of steam in boiler ($m^3/kg$) | Cumulative water absorbed (ml) Rice variety: Faro 27 | | | |
|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 |
| 1.0 | 1.148 | 115.0 | 128.3 | 132.1 | 139.7 |
| | 1.29 | 100.5 | 109.4 | 130.0 | 148.3 |
| | 1.433 | 93.7 | 125.3 | 130.3 | 136.0 |
| | 1.576 | 110.0 | 120.4 | 124.2 | 127.8 |
| 2.5 | 1.148 | 120.0 | 134.4 | 136.1 | 140.0 |
| | 1.29 | 7.5 | 105.7 | 128.5 | 148.3 |
| | 1.433 | 89.7 | 106.0 | 120.3 | 135.8 |
| | 1.576 | 100.4 | 125.6 | 128.4 | 135.0 |
| 4.0 | 1.148 | 123.4 | 130.0 | 134.5 | 145.2 |
| | 1.29 | 60.6 | 85.2 | 148.3 | 155.0 |
| | 1.433 | 75.3 | 79;.1 | 136.6 | 140.7 |
| | 1.576 | 88.1 | 144.0 | 148.5 | 143.5 |
| 5.5 | 1.148 | 107.1 | 143.0 | 152.5 | 165.1 |
| | 1.29 | 65.0 | 91.1 | 168.0 | 185.9 |
| | 1.433 | 70.6 | 119.6 | 142.3 | 165.6 |
| | 1.576 | 83.4 | 121.2 | 142.71 | 166.6 |

| Average pressure in steamer ($x10^4 N/m^2$) | Specific volume of steam in boiler ($m^3/kg$) | Cumulative water absorbed (ml) Rice variety: Faro 29 | | | |
|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 |
| 1.0 | 1.148 | 109.3 | 130.7 | 144.2 | 138.9 |
| | 1.29 | 86.6 | 121.4 | 130.2 | 149.1 |
| | 1.433 | 91.1 | 126.3 | 132.5 | 139.2 |
| | 1.576 | 101.0 | 123.5 | 128.8 | 131.5 |
| 2.5 | 1.148 | 106.4 | 134.7 | 138.4 | 146.8 |
| | 1.29 | 83.5 | 122.4 | 132.0 | 152.4 |
| | 1.433 | 87.0 | 121.2 | 132.4 | 141.0 |
| | 1.576 | 94.2 | 127.7 | 130.0 | 149.6 |
| 4.0 | 1.148 | 103.6 | 124.0 | 128.1 | 149.7 |
| | 1.29 | 45.0 | 84.3 | 162.4 | 194.8 |
| | 1.433 | 68.7 | 113.5 | 142.5 | 161.3 |
| | 1.576 | 77.9 | 122.3 | 131.4 | 142.7 |
| 5.5 | 1.148 | 87.4 | 134.9 | 140.7 | 168.0 |
| | 1.29 | 49.7 | 83.7 | 163.2 | 194.6 |
| | 1.433 | 71.1 | 118.0 | 142.4 | 166.2 |
| | 1.576 | 72.4 | 121.0 | 127.31 | 164.0 |

| Average pressure in steamer ($x10^4 N/m^2$) | Specific volume of steam in boiler ($m^3/kg$) | Cumulative water absorbed (ml) Rice variety: Faro 35 | | | |
|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 |
| 1.0 | 1.148 | 109.7 | 125.4 | 129.3 | 135.6 |
| | 1.29 | 100.0 | 110.2 | 135.6 | 140.2 |
| | 1.433 | 102.0 | 126.0 | 134.2 | 135.0 |
| | 1.576 | 107.4 | 110.4 | 115.2 | 128.8 |
| 2.5 | 1.148 | 128.5 | 118.3 | 113.6 | 140.2 |
| | 1.29 | 89.3 | 10.5 | 137.1 | 146.0 |
| | 1.433 | 91.0 | 110.2 | 125.7 | 138.7 |
| | 1.576 | 106.7 | 115.9 | 129.2 | 133.5 |
| 4.0 | 1.148 | 128.0 | 132.7 | 135.1 | 139.4 |
| | 1.29 | 77.8 | 90.4 | 145.2 | 155.7 |
| | 1.433 | 80.5 | 100.2 | 137.0 | 155.0 |
| | 1.576 | 95.2 | 106.3 | 113.5 | 148.3 |
| 5.5 | 1.148 | 72.3 | 101.4 | 128.3 | 139.1 |
| | 1.29 | 42.0 | 91.3 | 122.2 | 167.5 |
| | 1.433 | 50.2 | 90.6 | 109.8 | 152.8 |
| | 1.576 | 79.7 | 90.5 | 103.8 | 114.0 |

Also, water absorption capacity increased with increase in cooking duration for all the steam pressures although the rate of increment between the initial and final cooking durations were higher for higher levels of steam pressures. This could be as a result of the difference in severity of parboiling arising from the different levels of steam pressures used. Change in sorptive capacity of rice as a result of heat treatment which is usually influenced by the gelatinization temperatures of the kernel was reported (Bandyopadhay and Roy 1992; Ali and Bhattacharya 1991). However, no explanation was given about the parameters of the heat treatment that caused the change in the sorptive capacity of rice.

The cumulative water absorption capacity of rice decreased with increase in specific volume of steam between the 1.148 $m^3$/kg and 1.290 $m^3$/kg levels at any of the steam pressure and rice variety for the 10-30 min cooking durations. At the 5.5 x $10^4$ N/$m^2$ levels of steam pressure, the cumulative water absorption capacity of rice increased between the 1.148 $m^3$/kg and 1.290 $m^3$/kg levels of specific volume of steam at 40 min cooking duration but decreased between the second and fourth levels for almost all the rice varieties except Faro 21. This might be due to the fact that the rice parboiled with these 1.148 $m^3$/kg and 1.576 $m^3$/kg levels of specific volume of steam did not parboil properly as indicated by the presence of white bellied rice. Thus just like raw rice absorb water fast at the initial periods but slower at longer cooking durations which lead to bursting of the kernel at earlier periods (Bandyopadhay and Roy 1992), the improperly parboiled rice (steamed with the 1.148 and 1.576 $m^3$/kg levels of specific volumes of steam) absorbed more water and faster to reach it's equilibrium moisture content than the properly parboiled rice produced with the 1.290 and 1.433 $m^3$/kg levels. The comparatively severe starch gelatinization of the rice parboiled with the higher levels of specific volume of steam enables them to have more ability to withstand the bursting pressure exerted by the absorbed water.

All the rice varieties had higher water absorption capacity for lower levels of steam pressure at 10-30 min cooking duration but higher for higher levels of steam pressure at 40 min cooking duration. However, Faro 27 and Faro 29 absorbed more water at the final (40 min) cooking duration. The difference in the physiochemical and nutrient composition of the rice varieties might be responsible for this observation. As observed in table, rice varieties with higher protein content absorb less cumulative water. This assertion agrees with the findings of Joseph and Plank (1980), whereas Faro 27 and 29 absorbed more water than the long and short grain varieties (Faro 21 and Faro 35) did not conform to their findings. Also in a related study, Halick and Kely (1992) reported that the swelling numbers of long grain varieties differed from those of other types and that no definite differences among long grain varieties were observed.

### Comparison between the Treatment Means of Cumulative Water Absorption Capacity of Rice

The mean values of the water absorption capacities of rice below 40 min cooking periods at steam pressure $P_3$ (149.233 ml) and $P_4$ (154.069 ml) are not significantly different but significantly higher than $P_2$ (141.494 ml) and $P_2$ is also significant higher than $P_1$ (137.056 ml).

The mean values at the specific volume of steam $V_1$ (143.4 ml) and $V_3$ (145.318 ml) are not significantly different but are significantly lower than $V_4$ (137.838 ml). The cumulative water absorbed at the second specific volume of steam $V_2$ (155.238 ml) is significantly higher than all the others.

The mean values of the water absorption capacities for Faro 29 (155.613 ml) is significantly higher than Faro 27 (148.656 ml) but lower than Faro 21 (135.719 ml) and Faro 35 (135.613 ml) which are not significantly different from each other.

### Regression Equation

The following equations which predict cumulative water absorption capacity of rice at varying steam pressures and specific volume of steam were developed.

### Cumulative Water Absorption Capacity and Steam Pressure

$$C_w = -13.45P^3+99.65P^2-200.1P+262.2, \quad (1)$$

where: $C_w$ = cumulative water absorption capacity (ml); $P$ = steam pressure.

**Cumulative Water Absorption Capacity and Specific Volume of Steam**

$$C_w = 12.6V^3 - 102.1V^2 + 144.1V + 13.1, \qquad (2)$$

where: $V$ = specific volume of steam.

## Conclusion

Water absorption pattern of milled parboiled rice were dependent on rice variety and process steam properties such as steam pressure and specific volume of steam. The cumulative water absorption capacity of rice generally is higher for lower levels ($1.0 \times 10^4$ N/m$^2$ – $2.5 \times 10^4$ Nm$^2$) of steam pressures at the initial cooking durations of 10-20 min compared to the higher levels ($4.0 \times 10^4$ – $5.5 \times 10^4$ N/m$^2$) of steam pressures at the same duration. However, the water absorption trend reversed at higher cooking duration of 30 - 40 min.

Higher, cumulative water absorptions were obtained at the 1.148 m$^3$/kg and 1.576 m$^3$/kg levels of specific volume of steam at lower cooking durations of 10 – 20 mins while the level of specific volume of steam 1.290 m$^3$/kg had higher cumulative water absorption rate than the first and final levels at later cooking durations of 40 mins. Rice varieties Faro 27 and Faro 29 also absorbed more water at higher cooking duration of 40 min compared to the others. From these findings steam pressure levels $4.0 \times 10^4$ and $5.5 \times 10^4$ N/m$^2$ and specific volume of steam, 1.290 m$^3$/kg which have higher means of cumulative water absorption capacities are the optimum process parameters while Faro 27 and Faro 29 are selected as the best rice varieties with optimum water absorption rate at higher cooking duration of 30-40 min. This is because, at this higher cooking duration the rice kernels would have higher consistency and withstand bursting tendency resulting from the absorbed water pressure for longer time.

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