# Physical and Chemical Changes during Microwave Drying of Rice*

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Microwave drying of soaked rice was studied and compared with the conventional drying process. Soaked rice was treated in microwave oven at different processing microwave energy levels, initial moisture contents, and temperatures. The maximum value of drying rate for conventional hot air drying is up to 50 times lower than the rate observed for microwave drying. Amylographic gelatinization and pasting characteristics were used for the evaluation of microwave treatment influence on chemical and physicochemical characteristics of rice, parameters such as damaged and total starch content and water sorption capacity at 70 °C. It was found that microwave treatment did not affect the total starch content in rice, but the damaged starch content increased with the absorbed microwave energy and temperature of treatment, chiefly for the moisture content of 30 % and temperature of 100 °C. Amylographic characteristics and water sorption capacity showed minimal changes resulted from microwave drying of rice with the moisture content lower than 23 %. Compared to conventional drying, the course of rice microwave treatment was much faster and the main physical and chemical characteristics of rice were not changed.

Conventional rice drying is performed using heated air that transfers energy to the surface of grain kernels by convection. The energy transfer within the kernel is done by conduction. Water is desorbed into the drying air from the kernel surface, and a moisture gradient is established within the kernel, with water molecules diffusion toward the surface. The drying air temperature increase enhances the water desorption rate from the kernel surface, which results in a greater moisture gradient inside the kernel. Since a high internal moisture gradient can result in cracked or broken kernels, there is a practical upper limit of the drying temperature that can be used. Commercial dryers generally operate at temperatures around 60 °C and use the multiple passes through the dryer [1].

Microwave drying differs fundamentally from the conventional hot-air grain drying. During microwave drying, microwave energy is transmitted by waveguides into the chamber that contains the dried material – rice kernels. Microwaves penetrate the rice kernel, where highly polar water molecules preferentially absorb them. The high-energy water molecules rapidly diffuse through the rice kernel to the surface where they desorb.

The intensification of microwave drying can be achieved in combination with vacuum drying. The reduced pressure in the vacuum chamber lowers the concentration of water in the air surrounding the grain, thereby increasing the rate at which the water molecules desorb from the kernel surface. For a given rate of drying, reduced pressure lowers the temperature at which the grain is dried compared to the conditions required for drying at atmospheric pressure. Moisture is removed from the drying chamber by a vacuum and condenser. During microwave vacuum drying the moisture gradient within the rice kernel remains, but its magnitude is considerably lower than at conventional drying. The suitability of microwave-vacuum technology for drying freshly harvested green rice was tested in detail by *Wadsworth* [1]. Lower operating pressures in the dryer increased the drying rate and drying efficiency, whereas the rice temperature decreased.

The most important application of microwave rice drying is the process of rice parboiling. *Wadsworth et al.* [2] used a microwave-vacuum procedure for parboiled rice drying and investigated the effect of the process conditions (soaking, steaming, microwave power output, drying pressure, drying time, final moisture content) on the rate and efficiency of drying. The rice kernel drying rates were directly proportional to microwave power output and inversely proportional to

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the dryer operating pressures. At given conditions the drying rates were constant until the rice moisture content fell below 16 %. Parboiled rice could be rapidly dried up to the moisture content of 16 % without any significant affect on milling yields. However, below this value, head rice yield was highly dependent on the drying rate. Head rice are unbroken, whole kernels of rice and broken kernels that are at least three-fourths the length of an average unbroken kernel.

*Doos et al.* [3] reported the effects of microwave drying on milling output and technological properties (cooking and compositional quality) of milled rice. The authors found a significant negative correlation between the amount of head rice and duration of drying and a positive correlation between the drying time and the number of broken grains. Microwave drying resulted in a significant decrease in amylose content in a high amylose variety. Neither significant differences in proteins, fat, and ash contents were noted for both high and low amylose varieties, nor the microwave drying time significantly affected the optimum cooking time of the parboiled rice.

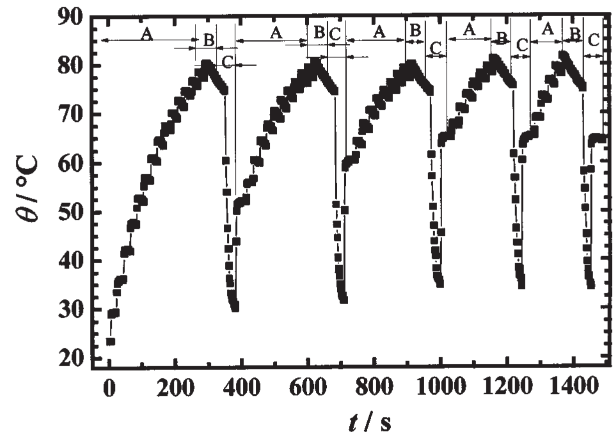


**Fig. 1.** Temperature *vs.* time dependence measured during microwave treatment of rice. $P$ = 90 W, final $\theta$ = 80 °C, initial moisture content 29.68 %, moisture content after 5 cycles 25.54 %. Drying cycle: A – microwave heating; B – relaxation in the microwave oven for 1 min; C – sample mixing and cooling outside the oven for 1 min.

## EXPERIMENTAL

Microwave oven Whirlpool MT 243/UKM 347 (Norrköpping, Sweden) with the frequency of 2450 MHz, power output of ($P$/W): 90, 160, 350, 500, 650, 750, 850, and 1000, and inner cavity volume of 25.4 $dm^3$ was used.

During the heating periods, the sample temperature was recorded using the NoEMI fibre-optic temperature system – tabletop unit ReFlex with 2 channels (Nortech Fibronic Inc., St-Jean-Baptiste, Quebec, Canada). Its general characteristics were as follows: ultra-fast general purpose miniprobe, temperature range from −40 °C to +250 °C, response time 0.25 s, computer interface RS-232-C, data logging function to spreadsheet-compatible file MS Excel, analogue output 0—20 mA. Teflon probe-guide was made to position the NoEMI optic probes into pre-determined locations inside the oven and in the samples measured.

The rice temperature increased rapidly as a result of exposure to microwave energy, but little drying occurred during this time. After reaching the required temperature, microwave power was switched off and the rice sample was retained in the oven cavity for 1 min. Then, the sample in the vessel was taken out of microwave oven, mixed, cooled to an ambient temperature (again for 1 min) and returned to the oven. This cycle of heating, mixing, and cooling was repeated five times. A typical course of time—temperature relationship during this treatment is illustrated in Fig. 1. Surface temperature of rice was measured by a probe situated 50 mm to the right from the middle, just in the position with the highest temperature. The location of temperature sensor was 2 mm below surface of sample. During the microwave experiments the following parameters were changed: the oven power output (90 W, 160 W, 350 W or 500 W); the final temperature of heated rice (60 °C, 80 °C, or 100 °C); and the initial moisture content in rice kernel (12 %, 23 %, or 30 %). The influence of microwave treatment on chemical and physicochemical characteristics of rice was evaluated by the following tests: damaged and total starch content – determined according to the Megazyme assays procedure [4], water sorption capacity at 70 °C [5], and amylographic gelatinization and pasting characteristics measurement [6].

At conventional drying of rice, approximately 200 g of rice was soaked in distilled water to the moisture content of 28.50 %. The sample was placed on a metallic sieve (diameter 200 mm, 1 mm mesh) of the upper shelf of laboratory hot-air drying oven and dried at 80 °C. Surface temperature and moisture content of the sample were repeatedly measured in 20 min intervals until a constant moisture content was achieved (about 7 h). The data obtained were used for quantitative description of the drying process.

200 g of wetted rice was placed in polyethylene dish to a centre of microwave oven and dried in a temperature mode at 80 °C. After reaching the desired temperature, microwave power was switched off, the rice sample was retained in the oven cavity for 1 min and than weighed immediately. The sample in the vessel was mixed and returned to the oven and cycle of heating, weighing, and mixing was repeated until constant decrease of weight was attained.

## RESULTS AND DISCUSSION

Drying curves and the dependence between the drying rate and moisture content were used for the comparison of conventional hot-air and microwave

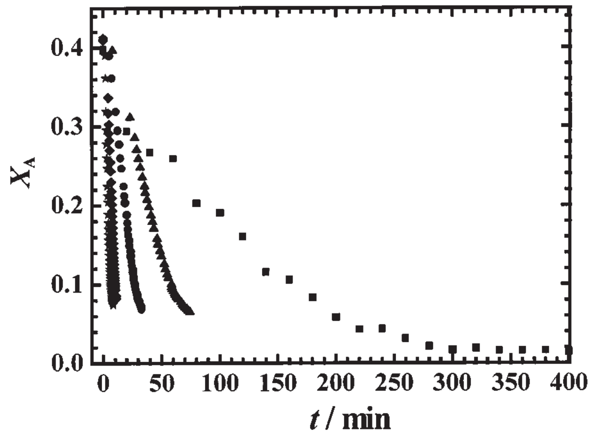


**Fig. 2.** Drying curves of rice. The moisture content *vs.* time dependence: squares – conventional drying, triangles – 90 W microwave drying, circles – 160 W microwave drying, diamonds – 350 W microwave drying, and stars – 500 W microwave drying.

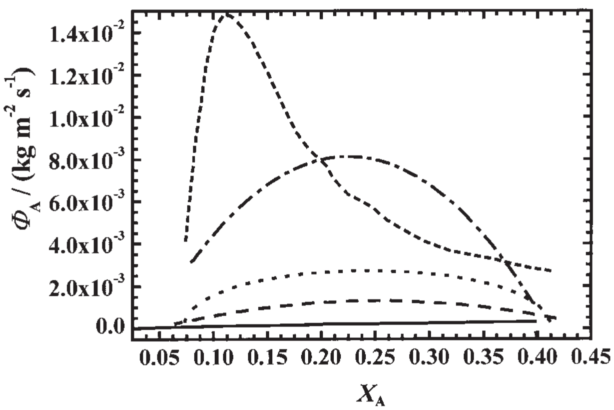


**Fig. 3.** Drying rate as a function of the moisture content in rice: solid line – conventional drying, dashed line – 90 W microwave drying, dotted line – 160 W microwave drying, dotted-dashed line – 350 W microwave drying, and dashed line (short dashes) – 500 W microwave drying.

drying of rice. The water relative mass fraction $X_A$ = 0.11 was achieved by conventional rice drying after 149 min, whereas by microwave treatment at 90 W power output after 56 min, at 160 W after 26 min, at 350 W after 10 min, and at 500 W after 6 min (Fig. 2). The drying rate *vs.* moisture content of rice dependences for microwave and hot-air drying are shown in Fig. 3. Conventional hot-air drying was characterized by a

**Table 1.** Total and Damaged Starch Content (TS and DS), Water Sorption Capacity (WU) and Amylograph Height (AH) in Rice Kernel as a Function of Oven Power Output ($P$), Drying Temperature ($\theta$), and Initial Moisture Content ($x_A$)

| $P$/W | $\theta$/°C | $x_A$/% | DS/% | TS/% | WU/% | AH/AU |
|---|---|---|---|---|---|---|
| 90 | 60 | 87.80 | 4.52 | 85.66 | 46.37 | 595 |
| 90 | 60 | 77.61 | 4.33 | 85.76 | 46.33 | 560 |
| 90 | 60 | 70.05 | 4.85 | 86.97 | 56.81 | 530 |
| 90 | 80 | 88.35 | 4.71 | 85.92 | 52.02 | 600 |
| 90 | 80 | 77.76 | 4.97 | 86.69 | 35.65 | 520 |
| 90 | 80 | 70.32 | 5.82 | 87.13 | 56.08 | 520 |
| 90 | 100 | 87.95 | 4.47 | 86.71 | 53.40 | 630 |
| 90 | 100 | 76.80 | 4.88 | 87.28 | 53.82 | 530 |
| 90 | 100 | 70.93 | 7.27 | 84.43 | 62.34 | 390 |
| 350 | 60 | 88.63 | 4.70 | 85.39 | 45.31 | 590 |
| 350 | 60 | 77.63 | 4.55 | 86.50 | 44.89 | 570 |
| 350 | 60 | 70.39 | 5.25 | 86.51 | 49.15 | 560 |
| 350 | 80 | 87.85 | 4.63 | 85.86 | 48.11 | 600 |
| 350 | 80 | 77.16 | 4.63 | 84.95 | 43.35 | 580 |
| 350 | 80 | 70.23 | 6.42 | 87.10 | 46.16 | 510 |
| 350 | 100 | 88.29 | 4.31 | 86.53 | 51.87 | 600 |
| 350 | 100 | 78.97 | 5.37 | 86.98 | 49.67 | 500 |
| 350 | 100 | 70.68 | 9.19 | 86.92 | 54.66 | 350 |
| 500 | 60 | 87.80 | 4.37 | 87.68 | 54.63 | 570 |
| 500 | 60 | 76.80 | 4.97 | 87.48 | 53.63 | 530 |
| 500 | 60 | 70.29 | 5.43 | 87.01 | 51.84 | 540 |
| 500 | 80 | 88.59 | 4.59 | 85.28 | 52.37 | 590 |
| 500 | 80 | 77.93 | 4.48 | 85.80 | 58.15 | 540 |
| 500 | 80 | 70.30 | 5.89 | 86.73 | 52.72 | 460 |
| 500 | 100 | 87.92 | 4.14 | 86.46 | 51.15 | 560 |
| 500 | 100 | 78.23 | 5.17 | 86.91 | 51.08 | 490 |
| 500 | 100 | 70.15 | 9.84 | 86.79 | 56.27 | – |
| Rice without microwave treatment | | | 5.57 | 87.20 | 41.99 | 570 |
| Standard deviation | | | 0.24 | 1.53 | 1.94 | 8.94 |
| Variation coefficient | | | 4.39 % | 1.75 % | 4.62 % | 1.51 % |

continuous decrease of the drying rate with decreasing moisture content in rice kernel. Microwave drying at 90 W, 160 W, and 350 W power output exhibited first increasing and then decreasing drying rate, passing through a maximum at water relative mass fraction of about $X_A = 0.225$. Microwave drying at 500 W power output was characterized by a mild increase with water relative mass fraction variation from 0.4 to 0.25. Then, a steep rise from 0.25 to 0.1 was observed, when the maximum drying rate was achieved, followed by a short period of the drying rate steep decrease. The maximum value of drying rate for conventional hot-air drying was 4.3 times lower than the drying rate for 90 W, 9.0 times lower for 160 W, 26.9 times lower for 350 W, and 48.9 times lower for 500 W microwave drying. The maximum drying rate increased with the oven power output. Compared to conventional drying, the rice drying by microwaves was much faster.

Table 1 presents the changes of total and damaged starch content during microwave treatment of rice. It is obvious that microwave treatment did not affect the total content of starch in rice. On the other hand, the damaged starch content in rice changed with temperature, power output, and initial moisture content of rice. The highest damaged starch content was observed at the highest initial moisture content and temperature studied.

The changes in water sorption capacity of microwave-treated rice are also shown in Table 1, water sorption capacity of treated samples is higher than the value of original dry rice. The increase of water sorption capacity is connected with the degree of starch gelatinization and rising of broken rice grains after microwave treatment. The changes in the amylograph height (in Amylographic units, AU) during microwave treatment of rice are shown in Table 1. An apparent decrease of amylograph height value with increasing temperature of microwave treatment and oven power output was observed at the initial moisture content of 30 %. The changes of the amylograph height were less pronounced at the initial moisture content of 23 % and were minimal at the initial moisture content of 11 %. These results are in agreement with those of *Halick* and *Kelly* [7].

## CONCLUSION

Drying curves and drying rate *vs.* moisture content relations were used for comparison of conventional hot-air and microwave drying of rice. The maximum drying rate was proportional to the oven power output. In this study, the microwave treatment influence on chemical and physicochemical characteristics of rice was also investigated. The results showed that microwave treatment did not affect the total content of starch in rice. On the other hand, the damaged starch content in rice kernel increased with absorbed microwave energy and temperature of treatment, chiefly for initial moisture content 30 % and drying temperature 100 ℃. Amylographic characteristics and water sorption capacity showed only minimum changes resulting from microwave drying of rice for initial moisture content lower than 23 %.

## SYMBOLS

| | | |
|---|---|---|
| AH | amylographic height | AU (Amylographic units) |
| DS | damaged starch content | % |
| $P$ | power output | W |
| $t$ | time | s |
| TS | total starch content | % |
| WU | water sorption capacity | % |
| $X_A$ | water relative mass fraction | 1 |
| $x_A$ | moisture content | % |
| $\Phi_A$ | drying rate | kg m$^{-2}$ s$^{-1}$ |
| $\theta$ | temperature | ℃ |

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