GAS PLASMA IRRADIATION OF RICE
II. Effect of Heat on Hydration and Cooking Characteristics[1]

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ABSTRACT

The hydration characteristics of rice are greatly changed by the simultaneous application of heat and reduced pressure to milled rice, i.e., by a heat-vacuum treatment, or by subjection to a gas plasma irradiation under comparable conditions of pressure, time of treatment, and temperature. The water absorption capacity is slightly greater for vacuum samples prepared at 45°C. and above than for samples irradiated at the same temperatures. Rices treated with vacuum, vacuum heat, or irradiation, cook faster and have different appearances than cooked untreated (raw) rice. A substantial reduction in cooking time of the treated materials is brought about by the use of a 15- to 20-minute presoak period.

In a previous paper (2) the authors reported that the gas plasma irradiation of milled rice increased its water absorption capacity so that the treated rice occupied a greater volume after a brief immersion in hot water than the nonirradiated vacuum-treated rice. Since temperatures attained during irradiation of the rice were higher than those

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found for vacuum treatment without irradiation, the use of the latter as a control was questioned. Irradiation caused the temperature to rise, whereas the straight vacuum treatment caused the temperature to drop during exposure to the experimental conditions.

The object of the present investigations was primarily to ascertain whether the application of heat during preparation of the vacuum control could increase the water absorption capacity of the treated material to the same level as rice irradiated under similar conditions of time, pressure, and temperature. The secondary purpose was to evaluate the samples prepared in this study, as well as those previously processed (2), in terms of cooking time and characteristics of the cooked rice.

Materials and Methods

Rice. The milled Bluebonnet-50 and Zenith rices used in the experiments were prepared from the same lots of 1958 foundation seed stocks described in the previous paper (2).

Treatment Apparatus. The same equipment was used for treatment of the rice, except that the irradiation chamber originally described (2) was modified in an attempt to control the temperature. The chamber was enclosed by a concentric glass jacket, 70 mm. o.d. by 53 cm. long. This outer cylinder was attached by rubber stoppers to the inner one. By means of two glass sidearms on the outer cylinder, water or steam at the desired temperature was passed through the jacket. Saturated free-flowing steam at atmospheric pressure was used to maintain 100°C.

Irradiation. In both the irradiation as well as the nonirradiated vacuum treatments, temperature was controlled by passing water or steam through the jacket. A longer time was required to attain a pressure of 2 mm. of mercury when the irradiation chamber was heated. This was due to the faster rate of vapor loss caused by the initially higher temperatures. Preliminary experiments showed the longest period required was about 4.5 minutes. Therefore, in the modified apparatus, a constant time of 5 minutes was used in all runs to allow for evacuation of the system. After this interval, the timing of the treatment was initiated. Thus a nominal treatment time of 30 minutes required 5 minutes for pump-down time plus the 30 minutes specified.

Temperature Measurement. For estimation of the temperatures attained during any treatment, thermocouples were taped on the surface of the irradiation chamber. The external use of thermocouples was necessary because the placement of a thermometer or thermocouple inside the treatment chamber during irradiation caused an abnormal glow discharge. Investigation showed that the jacket temperature varied from 1° to 4°C. above that of the rice as measured with a thermometer placed in the rice at the conclusion of a treatment.

Cooking Tests. Samples treated in this investigation and aliquots from those used for water uptake determinations (2) were appraised for cooking time and cooking characteristics. Rice (5 g.) was cooked in 60 ml. of distilled water over direct heat in a covered crystallizing dish 50 mm. o.d. by 70 mm. tall. Periodically, samples were withdrawn and pressed between glass slides, 2 by 3 in., to test for the presence of uncooked, white, hard centers. After they had disappeared the samples were subjectively checked to see if they were completely soft. The hard centers test had been suggested (1) as a method for cooking-time determination. When the samples were considered subjectively as done, the time was recorded and subsamples were given to a taste panel. The panel was instructed to rate the sample for doneness, flavor, odor, and appearance.

Using the same cooking method, larger-scale cooking-time appraisals were run on 60-g. quantities of rice in 350 ml. of water. This permitted comparison of cooking tests to doneness on a small scale versus those on a larger scale.

Results and Discussion

There was very little difference in amount of water uptake when determined by the previously established method (2), between rices irradiated for 30 minutes at 50 ma., 2 mm. of mercury, and the non-irradiated vacuum-heat treated samples. Although the data are not included here, the same parallelism existed between samples that had been similarly treated for 5 minutes. There was in general, a progressive increase in water uptake upon evaluation, when the treatment temperature was increased. The greatest single increase in water uptake occurred when the treatment temperature was raised from 95° to 100°C. The latter temperature was produced by free-flowing steam, whereas hot water was used for the former. Steam at 100°C. has a total heat capacity of about 1,150 Btu per lb., whereas water at 95°C. has only 161 Btu per lb. Thus steam is a much more efficient heating medium. This would explain the sharp increase in effect when the temperature was raised only 5°C. In addition, since at 95°C. the water contained in the rice is still in the liquid phase, the effect at this temperature is not as great as at 100° steam temperature. The expansion of water in the rice in going from water at 100°C. to steam at 100°C. is approximately 1,600-fold (specific volume of water at 100°C.

= 0.0167 cu. ft. per lb.; specific volume of steam at 100°C. = 26 cu. ft. per lb.). Thus, the tremendous expansion of steam could very well be an important factor responsible for the increased hydration properties induced in the product prepared at 100°C.

In earlier studies (2), a wide difference was shown in the hydration characteristics between the irradiated and the nonirradiated vacuum-treated samples. This difference was eliminated in the present study by application of heat during preparation of the vacuum control. This observation leads to the conclusion that at least the major effect of irradiation upon hydration is attributable to the heat produced by the gas plasma.

The initial point on Fig. 1 for the irradiated sample did not fall on the curve. Data for this point were obtained from rice treated in an unjacketed tube. Therefore, the temperature attained during treatment was entirely dependent upon heat produced during irradiation.

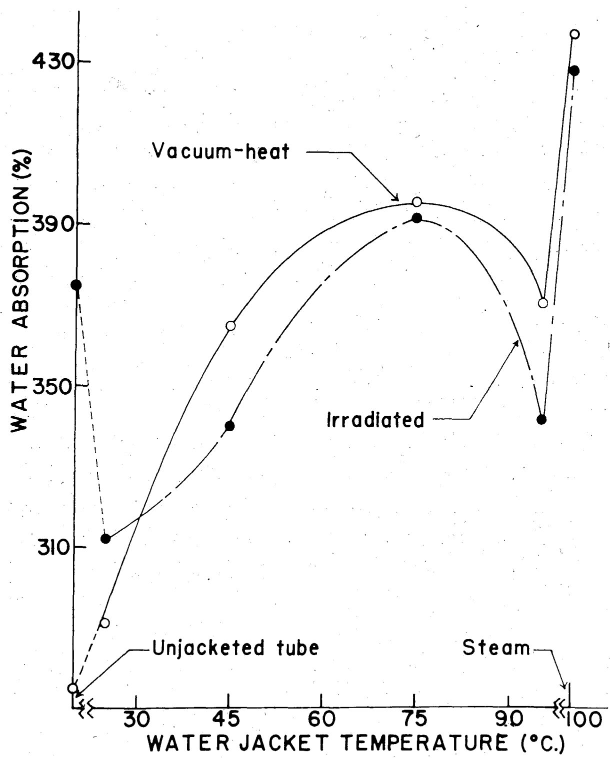

Fig. 1. Effect of temperature at time of irradiation (50 ma., 30 minutes, 2 mm. mercury), and vacuum treatment (0 ma., 30 minutes, 2 mm. mercury), upon the hydration characteristics of rice, Bluebonnet variety.

Thermocouples on the outside of the glass cylinder, immediately under the rice, indicated that 47°C. was the highest temperature attained after 30 minutes of treatment. Should this point on the curve be shifted laterally to 47°C., it would then fall in a much more logical place in relation to the rest of the curve.

An analogous situation existed for the first point on the curve for the nonirradiated sample. However, this point did not appear to be out of place. The temperature indicated by the thermocouples was about 23°C.; consequently it is almost correctly placed, as regards temperature, in its present position. The data from 5-minute treatment time samples confirmed this concept. Judging from the slope of the curve, in the 95° to 100°C. interval, it may be possible to get much greater changes in the amount of hydration by the use of temperatures above 100°C. Furthermore it may be assumed that more rapid and more efficient methods of heating, such as radiant or dielectric heating, could induce very high amounts of hydration when used for shorter times at lower temperatures.

The rapid loss of volatilized material that occurred during the treatments probably produced small fissures or channels for the escape of the volatilized material from the interior of the grains up to and through the surface. The resultant network could serve as ready pathways for more complete and rapid hydration when grains were immersed in water. Some credence for this theory comes from the following observations: the surfaces of all the treated rice grains were uniformly checked; the grains had lost their translucency and had become opaque; the surfaces of the cooked treated grains were very rough and irregular; and the cooked grains were greatly enlarged.

To accomplish the secondary objective of this study, cooking tests were run to determine if the times required for cooking to doneness were related to the hydration capacities shown by water-uptake determinations, Tables I and II. The samples which had high water absorption capacities failed to show any appreciable difference in cooking times as compared with those with the lower hydratabilities. Additional observations made on the cooking methods and results are as follows:

1. Cooking in a large excess of water resulted in excessive breakage, especially when the rice was presoaked.

2. The hard centers test did not show any consistent relationship to subjective completeness in cooking.

3. Cooking tests on 5-g. quantities of rice generally required about the same cooking time as those done on 60-g. amounts.

TABLE I

COOKING TIME OF RICE SAMPLES TREATED FOR 5 MINUTES AT 2 MM. MERCURY, AND AT VARIOUS LEVELS OF CURRENT INTENSITIES

Irradiation Intensity	Cooking Times at 100° C.							
	Bluebonnet				Zenith			
	20-Minute PS[a]		No PS		20-Minute PS		No PS	
	No HC[b]	Done	No HC	Done	No HC	Done	No HC	Done
ma	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*
Untreated	17.5	20.0	20.0	20.0	12.0	14.2	17.0	24.0
0	1.7	9.2	18.0	18.0	4.7	7.7	18.0	24.0
25	1.7	9.5	19.0	19.0	5.0	7.7	18.0	23.2
50	1.0	6.5	18.5	18.5	2.0	8.0	16.7	20.7
75	2.2	7.2	19.0	19.0	2.0	7.7	16.0	20.0
110	2.7	7.0	16.5	16.5	2.2	7.0	13.0	18.0
145	1.2	8.0	17.7	17.7	...	...	....	....
150	3.5	...	15.7	....	4.0	9.0	12.0	18.0
175	3.7	6.7	16.5	16.5	8.0	8.5	13.0	19.0
210	3.2	8.0	....	....	6.0	9.0	12.2	18.0

[a] PS = presoaking.
[b] HC = hard centers.

4. The benefits of the treatments (vacuum, vacuum-heat, or irradiation) were more evident in cooking-time determinations, when a presoak was used. Limited observations indicate that 15 minutes was the minimum presoak time required.

5. At higher irradiation intensities where browning was produced and/or where rice was off-color, off-flavors and off-odors were detectable in the cooked samples.

TABLE II

COOKING TIME AFTER 20 MINUTES' PRESOAK OF BLUEBONNET RICE IRRADIATED FOR 5 OR 30 MINUTES AT 50 MA. INTENSITY AND AT 2 MM. MERCURY; AND OF NONIRRADIATED VACUUM-TREATED CONTROLS PREPARED AT VARIOUS TEMPERATURES (5 or 30 Minutes at 0 ma., 2 mm. Mercury)

Treatment Temperature	Cooking Times at 100° C.							
	Treated 5 Minutes				Treated 30 Minutes			
	Nonirradiated		Irradiated		Nonirradiated		Irradiated	
	No HC[a]	Done	No HC	Done	No HC	Done	No HC	Done
°C	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*	*minutes*
Conv.[b]	3.25	7.25	3.0	8.0	...	...	...	...
Conv.	....	...	...	...	4.5	8.0	8.5	8.5
25	2.7	8.5	3.5	8.5	5.0	9.0	5.5	9.0
45	3.5	6.0	6.0	8.2	3.5	7.5	7.7	7.7
75	3.0	9.0	4.0	8.5	4.0	8.0	3.5	7.0
95	3.2	8.2	2.5	7.2	3.7	7.0	3.5	8.5
100[c]	2.7	8.0	5.0	9.0	1.7	6.2	4.2	9.7

[a] HC = hard centers.
[b] Conventional treatment apparatus.
[c] Heated by steam rather than by water.

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