GAS PLASMA IRRADIATION OF RICE
I. Hydration Characteristics[1]

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ABSTRACT

Milled, whole-grain rice, that was subjected to a gas-plasma irradiation, established by a 60-cycle power source, at a pressure that was low enough to permit the generation of a (glow) discharge across electrodes, showed a marked increase in the amount of water that could be absorbed. A study of the effect of the major operating variables revealed: 1) with the time and pressure constant at 5 minutes and 2 mm. of mercury respectively, maximum changes in hydration characteristics occurred at about 175 ma. for Zenith variety and 150 ma. for Bluebonnet 50 rice; 2) within the pressure range of 2 mm. to 8 mm. of mercury with a current of 25 ma. to 75 ma. for 5 minutes, pressure during treatment had no great effect upon changing the water absorptive capacity; 3) at 50 ma. and 2 mm. of mercury pressure, any increase in treatment time over 45 minutes for Bluebonnet variety and 70 minutes for Zenith was inefficient in increasing the amount of water absorption.

The difference between the water-holding capacity of irradiated and nonirradiated vacuum-treated controls may possibly be explained by the wide divergence between the temperatures attained during their preparation.

There has been a very great and widespread interest in the quality of milled rice (1,2,6,8). One of the most important rice quality factors is the speed and extent of hydration that occurs upon immersion in water. To a great extent, this influences cooking time and texture of the prepared product. The effects of storing (5), variety and heating (7), freezing (9), and parboiling (3) upon hydration have been studied extensively. Stone (13) recently reported on a low-energy radiation procedure that greatly increased the water absorbancy of cotton, linters, and fibers. Similar changes were shown earlier (4) for soybeans. Brown *et al.* (4) speculated on the possibility of using irradiation to shorten the cooking time required for dehydrated seeds used as foods. The present investigation reports on the three most important operating variables of gas-plasma irradiation and their effects on the hydration characteristics of two varieties of rice. These include time and intensity of irradiation and the range of pressures used in the treatments.

Materials

Bluebonnet 50 and Zenith varieties of rice, 1958 crop of foundation

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seed, were obtained near Crowley, Louisiana. Combined rice was dried immediately after harvesting, under ambient conditions, and stored in sealed cans at about 15°C. The rice was milled and whole grains were separated by standard methods (10,11,12). Glow discharge equipment was similar to that recommended by Brown *et al.* (4). The irradiation chamber consisted of a borosilicate glass tube, 51 mm. o.d. by 61 cm. long. At each end of the tube, a black iron coupling, ¾ in. nominal diameter, connected to a rubber stopper by a black iron nipple, was used for an electrode (Fig. 1). This type of metal was used to minimize sputtering of the electrodes during the treatments. High voltages were

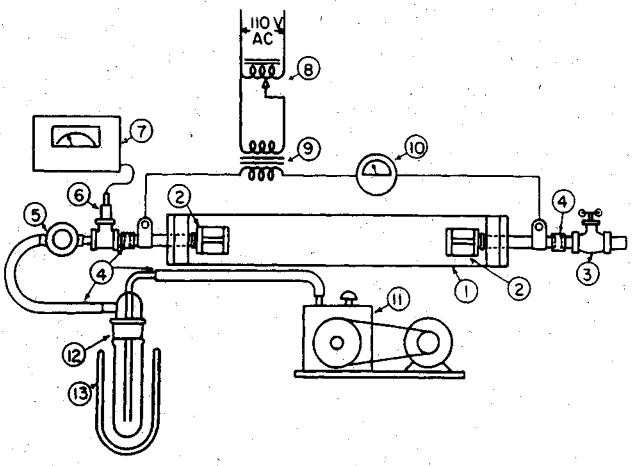

Fig. 1. Schematic drawing of gas-plasma irradiation apparatus: 1, glass tube; 2, black iron couplings (electrodes) mounted in rubber stoppers by means of short nipples; 3, needle valve; 4, rubber pressure tubing; 5, two-way solenoid valve; 6, vacuum gage tube or sensing element; 7, absolute pressure indicator; 8, variable transformer; 9, luminous-tube transformer; 10, AC milliammeter; 11, vacuum pump; 12, freeze-trap; 13, Dewar flask.

obtained from luminous-tube transformers. For currents in the range of 50 to 145 ma., a transformer rated at 6000 v. and 120 ma. (Jefferson Electric Co., Bellwood, Ill.)[4] was used. For lower intensities a 5000-v., 60-ma. source was utilized; whereas two of the larger transformers, connected in parallel or a 12,000-v., 15 kva. transformer (Westinghouse) were employed for higher intensities. The current was regulated by connecting the primary side of the transformer to a variable transformer, such as a Powerstat.

[4]Mention of trade names, equipment, or suppliers does not constitute endorsement by the Department of Agriculture over others not mentioned.

Methods

A 30.0-g. sample of rice was uniformly spread along the bottom of the treatment chamber. Rubber stoppers containing the electrodes were used to seal the ends of the treatment chamber, and other required equipment was connected as indicated in Fig. 1. Zero time was recorded and irradiation was initiated as soon as the desired pressure was established. When the vacuum controls were prepared without being irradiated, the same timing procedure was used. The treated samples, i.e., both the irradiated and the nonirradiated vacuum-treated rices, were placed in sealed containers and stored at room temperature.

There were three major sets of experiments on the effects of operating variables — current intensity, pressure in the system, and treatment time — on the hydration characteristics of whole-grain milled rice. For the study of intensity, a pressure of 2 mm. of mercury and a treatment time of 5 minutes were kept constant; for pressure, 50 ma. and 5 minutes were constant; and for time, the intensity and pressure were maintained at 50 ma. and 2 mm. of mercury.

The water-absorption values for the treated rices were determined according to a previously described procedure (7). The rice and water were first held at room temperature (about 24°C.) for 30 minutes before they were immersed in a water bath at 90°C. for 10 minutes. These values were also obtained at 70°C. Since they were generally of a lower magnitude but parallel to those for 90°C., only the latter are reported. Water absorption values are expressed on a dry-weight basis and represent the average of at least two determinations.

$$\text{Water absorption (\%)} = \frac{\text{weight of moisture in cooked rice}}{\text{weight of dry material in cooked rice}} \times 100$$

The values reported for total solids lost to the cooking water were obtained by difference from a materials balance. In conjunction with these calculations, moisture contents of the original milled rice samples were determined by the AMS method (14).

Results

Current Intensity. There was a progressive increase in amount of water absorption of Zenith variety rice, as the irradiation intensity was increased up to about 175 ma. (Fig. 2). The loss of total solids to the treating water generally paralleled the changes in water absorption up to a current of 110 ma. Thereafter the solids loss diminished as the intensity increased. This change apparently was related to the texture of the hydrated rice: thus when the solids loss decreased there was less cohesiveness between the cooked grains. Based upon hydration, the

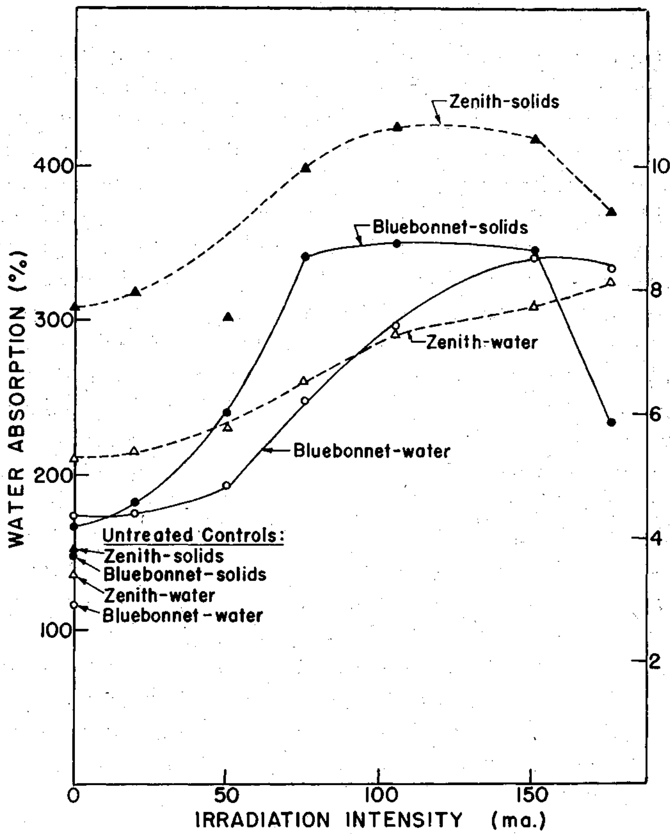

Fig. 2. Hydration characteristics of rice as influenced by irradiation for 5 minutes at 2 mm. of mercury.

maximum for Bluebonnet was reached at 150 ma. The change in amount of solids loss occurred at the same intensity as it did in the case of Zenith. Since treatment time and pressure were constant in this study, the effects of vacuum on hydration were constant regardless of current intensity. Thus the improvement in water absorption with progressively higher radiation doses was attributable to the effects of irradiation.

An intensity of 175 ma. at 2 mm. of mercury for 5 minutes was the highest level that could be used without browning the rice: at higher levels all of the rice became distinctly darker with a scattered occurrence of browned grains. However, using 15 g. of rice rather than 30 g. per treatment, it was possible to treat at intensities of about 210 ma. with less browning.

In many instances a scorched odor was noted after irradiation. Except when the odor was initially very pronounced, it gradually became less evident with storage. However, excluding those samples treated at 210 ma., no off-odor was detectable after they were hydrated under the described conditions.

Pressure. There was no great difference in hydration characteristics caused by varying pressure when rice was treated at 25 to 75 ma. for 5 minutes, in the pressure range of 2 to 8 mm. of mercury.

TABLE I

EFFECT OF TREATMENT PRESSURE AND CURRENT INTENSITY UPON THE HYDRATION CHARACTERISTICS OF RICE TREATED FOR 5 MINUTES

Variety	Irradiation Intensity	Water Absorption at Different mm. Pressures of Mercury			
		2	2.5	4	8
	ma	%	%	%	%
Bluebonnet	0	178	...	171	160
	25	176	...	173	194
	50	235	...	206	207
	75	248	...	224	217
Zenith	0[a,b]	...	119	103	72
	0[a]	...	121	114	110
	0	216	...	200	190
	25	215	...	202	204
	50	232	...	216	238
	75	256	...	239	239

[a] Water absorption determined 30 minutes at room temperature, 10 minutes at 70°C.
[b] Bleed located close to vacuum pump.

The vacuum pump capacity was, within certain limits, an important factor. The pressure increased slightly once irradiation was initiated, owing to increase in the gas temperature and in the increased out-gassing of the rice. A pump of still larger capacity minimized this, but even the expedient of employing a pumping capacity about 2.5 times greater did not correct this difficulty. The rate of gas or vapor evolution from the rice therefore must be a limiting factor. Thus, with a given pump, a Bluebonnet rice with 15.5% moisture required up to 3 minutes to reach 2 mm. of mercury pressure, whereas at 10.5% moisture, only 10 seconds were required.

The location of the pressure regulator, which in this case was a needle valve to admit air, was critical. When air was bled over the rice, using the set-up described in Fig. 1, higher water absorption values were obtained (Table I), especially at the highest pressure (8 mm. of mercury), than when air was admitted to the line connecting the tube to the vacuum pump, i.e., between No. 6 and No. 2, Fig. 1.

Time. At 50 ma. and 2 mm. of mercury pressure, any increase in

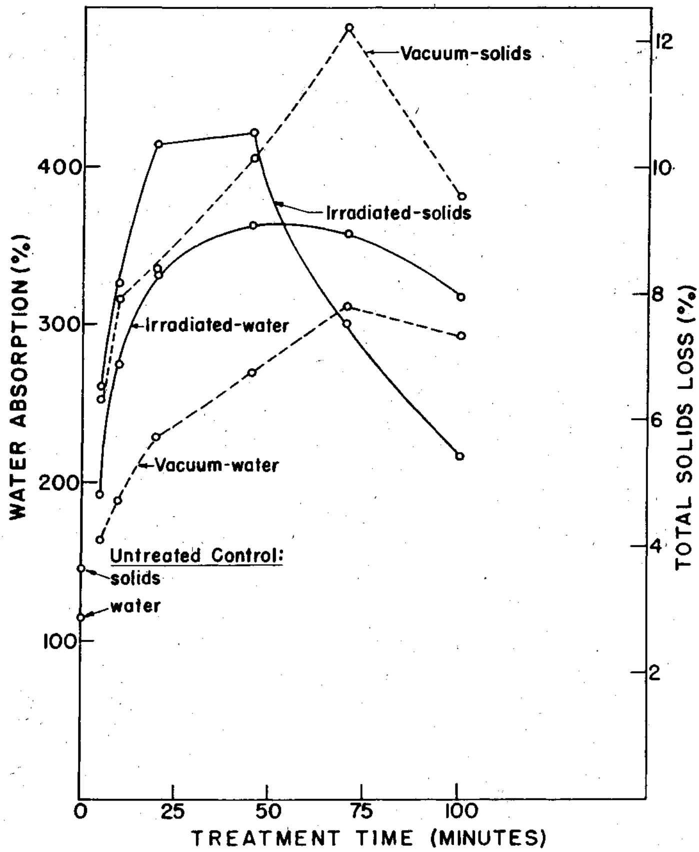

Fig. 3. Effect of duration of treatment upon the hydration characteristics of Bluebonnet variety rice (treated at 2 mm. of mercury and 50 ma. or 0 ma.).

treatment time over 45 minutes for Bluebonnet variety and 70 minutes for Zenith was ineffective in imparting higher water-absorption values (Figs. 3 and 4).

In both instances the next higher time level did not affect the amount of water absorption, but it did result in a great decrease in the amount of total solids loss to the treating water. This was also accompanied by a change in the texture, identical to the change noted in the intensity experiments previously described.

The effects of vacuum, *per se*, on both varieties apparently leveled off at about 70 minutes. However, at 45 minutes and above, vacuum played a more important part than irradiation in the increase in water absorption of irradiated Bluebonnet. This occurred because absorption in the irradiated samples did not increase as rapidly as in those

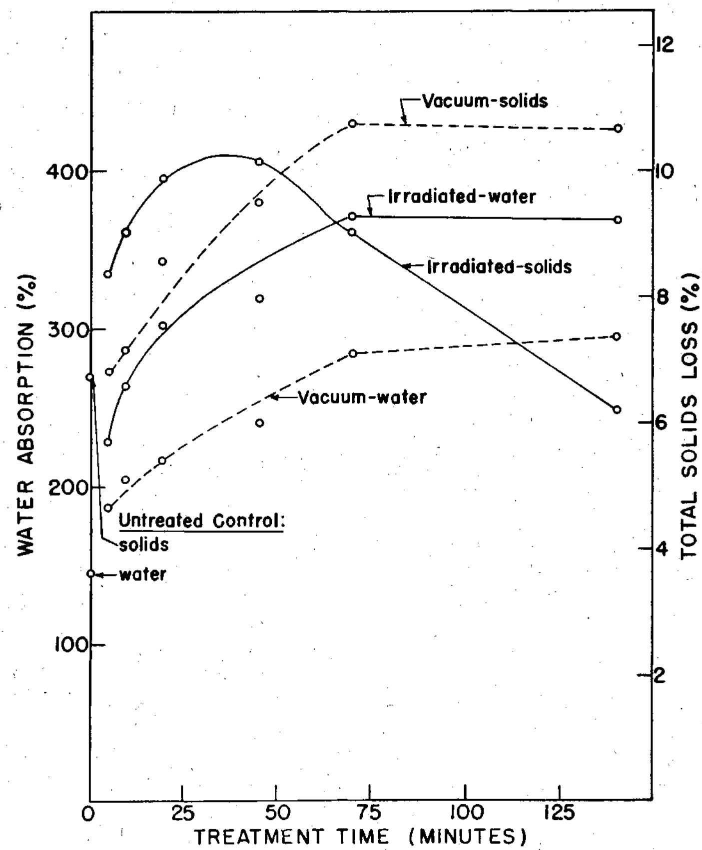

Fig. 4. Effect of duration of treatment upon the hydration characteristics of Zenith variety rice (treated at 2 mm. of mercury and 50 ma. or 0 ma.).

treated with only vacuum above 45 minutes.

Viscosity and Susceptibility to Beta-Amylase. Preliminary experiments (using a sample of Bluebonnet treated for 10 minutes at 2 mm. of mercury and at an intensity of 50 ma.) indicate that the starch, which constitutes about 90% of the dry weight of the rice, is not greatly changed by irradiation. This evidence was obtained from amylograph viscosity evaluations and tests for beta-amylase susceptibility, where there were no appreciable differences between the behavior of the treated rice and its control.

Discussion

Difficulty was experienced in reproducing exact water-absorption values under identical treatment conditions. A statistical analysis showed that of the variability that occurred, 75% was due to the treatments *per se*, and the other 25% existed in the evaluation process. When the same operating variables were used with two different assemblies (i.e., these rigs differed in that different transformers, vacuum pumps, and irradiation chambers were used), there was a highly significant difference in water absorption of the treated samples. However, the magnitude of the rig-effect was constant for various treatments tested. While some difficulty occurred in reproducing absolute values, no problem existed in the reproduction of trends. It was possible to obtain peak values of water absorption for the same duration of irradiation when the experiment was replicated. The other points disclosed by the statistical analysis were: 1) the effect of irradiation was highly significantly more pronounced on Bluebonnet than on Zenith; and 2) the standard deviation of means of duplicate determinations (including variability for both replication and evaluation) was about 12. Thus for determining whether two treatments were different, a difference of twice the standard error of differences, or 34 ($= 2\,\sigma\bar{d} = 2\sqrt{2}\,\sigma\bar{x} = 2\sqrt{2}\ 12$), was considered to be statistically significant.

When each of the operating variables — time, intensity, and pressure — was changed as the other two were kept constant, peak values for water absorption were produced. Consequently an assumption was made that when these optima were used in combination, a product with even greater water-holding capacity would result. Such an experiment run at 150 or 175 ma. for 25 minutes at 2 mm. of mercury did not produce this anticipated result on either variety. In fact, it gave lower water-holding capacities. Additional runs were made with Bluebonnet, holding 145 ma. and 2 mm. of mercury constant and varying treatment times up to 30 minutes: the maximum occurred at about 15 minutes.

Heat is generated in the glow discharge process. As a result, the temperature of the tube walls and the materials exposed to the discharge will increase to a point where the losses are equal to the input. This point will depend on the kind of gas, gas pressure, and current. Thus with the time held constant, greater amounts of heat are produced at the higher current intensities. With the latter constant, longer times permit the temperature to rise since such an equilibrium has not been attained. This may explain the decreased water absorption and total solids loss for times greater than 15 minutes at or above 145 ma., or for periods longer than 70 minutes at 50 ma. Possibly the absorption of heat by the rice at these time and current combinations could have partially sealed the surface of the rice grains and this could have retarded water absorption. This hypothesis is also useful in explaining why there were decreased losses in total solids to the treating water, and why there were textural changes on the surface of the rice, i.e., changes in cohesiveness, under these conditions. For example, Bluebonnet treated for 15 minutes at 145 ma. and 2 mm. of mercury lost 12.7% solids to the cooking water during the hydration test, whereas 30 minutes under the same conditions gave a 5.7% loss when hydrated.

In these studies the use of a nonirradiated vacuum-treated rice represented only a poor approximation of a "true control." The major point of divergence was the temperature difference during treatment. In the case of the nonirradiated sample, the temperature gradually dropped owing to evaporative cooling; whereas during irradiation the temperature rose. Thus it cannot be discounted that the difference between these samples may have been due largely and possibly entirely to the effects of heat. These heat effects will be described in a subsequent paper, as will the results of cooking tests. Also the possible control of cohesiveness by the use of operating variables beyond those that produced maxima for water absorption will be included.

In summary, these studies have shown that milled rice, upon gas-plasma irradiation, becomes chalky, opaque, and extensively checked. The treatment resulted in a marked increase in the amount of water absorption and a greater swollen appearance of the irradiated rice, over that of the vacuum control, when they were immersed in hot water. Similar but much less extensive changes in appearance and hydration characteristics were evident in the nonirradiated vacuum-treated controls. In view of these changes, the use of treatment methods described should be studied to reveal their potential for the production of convenience rice products, i.e., products that cook faster or that have modified culinary properties.

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