Gamma-radiation Effects on Taiwan-produced Rice-grains

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Gamma-radiation effects on Taiwan-produced rice-grains have been investigated and discussed to find an advantageous application of radiation processing on the preservation of rice-grains. This paper deals with the results obtained from the three major kinds of rice-grains which were gamma-irradiated and stored.

The factors of contaminated microorganisms on the rice-grains, chemical analysis of rice-ingredients, activity of α -amylase in the rice-grains, germination-rate of the rice-grains, rice-insect fertility and cooking quality of the hulled rice were studied. Among them, the following factors were considered as the main results.

1. Gamma-irradiation could reduce the contaminated microorganisms remarkably as the gamma-dose was raised over 100 krad, *e.g.*, reduction of the survivals of microorganisms to 19.62 ~ 39.76% with 100 krad, to 5.41 ~ 9.09% with 300 krad, to 0.58 ~ 0.81% with 1 Mrad during the twelve months storage period.
2. Some fluctuations on the fat acidity and the contents of reducing sugars and thiamine in the irradiated rice-grains were observed in the period of twelve months preservation at 20 ~ 30°C.
3. The germination of rice-grains was reduced considerably with the irradiated samples exposed to a gamma-dose over 50 krad.
4. No deleterious effects on rice-insect fertility on the irradiated rice-grains with a 50 krad gamma-dose occurred during the twenty-four months storage period, unlike those of the unirradiated ones and the irradiated ones with gamma-doses below 30 krad.
5. No significant changes were found on the cooking quality of the hulled rices irradiated below a gamma-dose of 300 krad and stored for twenty-four months at 20 ~ 30°C.

An annual agricultural product of 2.5 million tons of rice-grains provides the people in Taiwan with the most important staple food. However, investigations have revealed that 38%⁽¹⁾ of the total rice-grains was affected by mould-damage and more than 6%^(2,3) by insect-damage during the post-harvest storage in Taiwan. This extensive loss of rice-grains has stimulated a great deal of research on minimizing these damages, such as spraying insecticides of pyrethrins, malathion and parathion *etc.* on rice-grains or fumigating rice-grains with methyl bromide, ethylene oxide and hydrogen cyanide. However, these processes cause troublesome effects through the intake of hazardous residues of the contaminated insecticides and fumigating chemicals to the human body. Gamma-radiation process-

ing, therefore, comes into the consideration to control all insects, microorganisms and enzymatic metabolisms, with the merits of simplifying the whole treating process, minimizing the processing time, leaving no detrimental residue and for a reasonable radiation cost. The possibility to reduce the use of insecticides and fumigating chemicals with consequent potential reduction of their residues in rice-grains has attracted a big interest in application of the radiation process for the preservation of rice-grains. Through many pioneered works,^(4~8) gamma-radiation processing is believed to be an ideal method for the preservation of rice-grains and many other food-stuffs. As to wholesomeness of the irradiated rice-grains, irradiated rice has been already accepted up to the permissible maximum gamma-dose of 100

krad by the joint FAO/IAEA/WHO expert committee⁹⁾ in 1977.

This work was carried out to investigate the effects of radiation of Taiwan-produced rice-grains and also to find the optimum level of large scale radiation of rice-grains for their preservation. This paper deals with experimental data on gamma-radiation, chemical analysis of rice-ingredients during preservation, the activity of α -amylase, germination of rice-grains, rice-insect fertility and the cooking quality of the hulled rice.

EXPERIMENTAL

1. *Raw material.* Three major kinds of Taiwan produced rice-grains, *e.g.*, Taichung-1 (Tsailai-rice), Tainan-5 (Ponlai rice) and Taichung-46 (glutinous rice) were used, with 20 kg of each kind as the experimental raw materials. They were supplied by the Taiwan Provincial Agricultural Research Institute after being harvested and dried in its Taichung Experimental Station located in the middle of Taiwan. The moisture content (by wt.%) of these rice-grains was as follows:

Taichung-1	11.5%
Tainan-5	12.1%
Taichung-46	13.3%

2. Experimental procedure.

(1) *Preparation of rice-grain samples for gamma-irradiation.* 160 g each of the respective rice-grains was packed in a double-layer polyethylene bag in air followed by tightly sealing the bag-mouth with an electric heat sealer.

(2) *Gamma-irradiation.* The packaged rice-grain bags were irradiated in the 1,300 Ci Co-60 apparatus in the Union-Industrial Research Laboratories, ITRI, with a dose-rate of 52 krad/h for the programmed total gamma-doses in the range of 10 krad ~ 1 Mrad.

(3) *Preservation test of rice-grains.* All rice-grains submitted to the preservation test were stored in a chamber at 20°C and a well air-ventilated room with a relative humidity of 60% in both cases.

(4) *Method for measuring the contaminated microorganisms on the surface of rice-grains.* One hundred pellets of rice-grains were put into a glass-stoppered test-tube which contained 10 ml of completely sterilized water. After vibrating the whole tube for 3 hours, 1 ml of the water was

pipetted into another test-tube containing 9 ml of the same sterilized water as the first dilution. The first diluted solution was then subjected to another 1.5 minutes' vibration, or was pipetted into a petri-dish containing a nutrient agar-solution for cultivating the contaminated microorganisms in an incubator at 30°C for 3 days.¹⁰⁾ Five or six repetitions of this dilution process were preferred for this measuring test. The total number of the contaminated microorganisms was calculated by multiplying the numbers counted in the colony, which were obtained from 1 ml of the final dilution water, with the term of 10^{n+1} , in which n is the number of dilution repetitions.

(5) *Determination of fat acidity in rice-grains.*¹¹⁾ About 10 g of powdered hulled rice (42 mesh) and 40 ml of benzene were added to a 50 ml glass-stoppered Erlenmeyer flask and the mixture was shaken for 45 minutes. After filtering, 10 ml of the filtered benzene solution was mixed with 10 ml of 0.04% phenolphthalein ethanol solution and then the whole mixed solution was titrated with 0.0178 N KOH solution. Since 1 ml of 0.0178 N solution is equivalent to 1 mg of KOH, the content of fatty acids was expressed as the weight (mg) of KOH per 100 g of rice-grains. The initial end point of the titration was matchable to the coloration of the first indicator solution which was prepared by adding a few drops of 0.5% $K_2Cr_2O_7$ solution to 50 ml of water. The titration was continued to the end point in which the coloration should be identical to that of the second indicator solution prepared by adding 2.5 ml of 0.01% $KMnO_4$ solution to the first indicator solution.

(6) *Determination of reducing sugar content in rice-grains.* About 10 g powdered hulled rice (42 mesh) and 200 ml of distilled water were put together into a 500 ml Erlenmeyer flask. After vibrating for 2 hours, the mixture of water and rice was separated by centrifuging (500 rpm, 10 min). The content of reducing sugars in the water fraction was determined according to the modified Somogyi method.¹²⁾

(7) *Determination of thiamine (Vitamin B₁) content in rice-grains.*¹³⁾ 10 g of the powdered hulled rice was boiled with 75 ml of 0.2 N H_2SO_4 in a 200 ml Erlenmeyer flask for 15 minutes. 45 ml of 0.3 N $Ba(OH)_2$ solution and 0.5 ml of bromocresol green indicator*¹ were added to the boiled mixture on cooling. The whole mixture was then titrated with 0.2 N NaOH solution until the solution color became blue (pH 5.0 ~ 5.4). Diluting the titrated solution to 120 ml in a graduated cylinder and filtering the solution were sequentially followed. 80 ml of the filtrate and 50 ml of phenol ethanol solution (0.4 g phenol in 1 liter 95% ethanol) were mixed in a 500 ml Erlenmeyer flask and the mixture was titrated with 0.2 N NaOH solution using two drops of phenol-red indicator*² until the solution coloration changed to red. Another prepared mixed so-

*¹ Bromocresol green indicator: 50 mg of bromocresol green was dissolved in 10 ml of 95% ethanol and the solution was diluted to 100 ml with water.

*² Phenol-red indicator: 50 mg of phenol-red was dissolved in 10 ml of 95% ethanol and the solution was diluted to 100 ml with water.

lution*³ and 5 ml of xylene-isooctane (1:1 vol. ratio) were added to this titrated solution which was then shaken vigorously for 45 minutes. The top-layer was separated for the determination of the thiamine content by measuring its optical absorbance with 520nm wavelength visible light. The results were checked with the standard thiamine solution's content absorbance chart and the content of thiamine was consequently obtained.

(8) *Determination of the activity of α -amylase.* 25 seeds of the rice-grains were soaked with a disinfectant of 0.5% NaOCl solution for 20 minutes followed by complete washing with sterilized water. These rice-grains were then put on a petri-dish (ϕ 9cm) for their germination at a temperature of 33°C with 5 ml of sterilized water in a few days. The germs of rice-grains (about 1 cm length of germ) were crushed in a mortar with a small volume (1~2 ml) of sodium acetate buffer solution (pH: 4.8). The whole mixture (5 ml), including the rinsing buffer solution, was centrifuged (5000 rpm) for 15 minutes to separate the solid sludge from the α -amylase extracted liquid.¹⁴⁾ 0.05 ml of this liquid was pipetted into a flat-bottom test tube (ϕ 2.2 cm, height 9 cm) containing 0.95 ml of sterilized water and 1 ml of 0.2% potato starch solution.*⁴ The whole mixture was then kept at 30°C for 1 minute to digest the starch solution with the α -amylase. This digestion was stopped by adding 1 ml of KI-I₂ solution.*⁵ The solution was diluted with distilled water to 13 ml volume and its optical density measured at a wavelength of 620 nm. The activity of α -amylase was determined by the abundance of α -amylase-unit in 25 seeds of rice-grains calculated from the following formula.¹⁵⁾

$$\alpha\text{-amylase unit} = \frac{\Delta A \times V}{T \times V'}$$

V : Total volume of α -amylase extracted liquid (5 ml)

V' : Volume of the α -amylase extracted liquid used for digesting the potato-starch solution (0.05 ml)

T : Time of digestion (1 min)

ΔA : The different of the measured optical density between the α -amylase digested solution and the blank solution.

(9) *Germination-test.* 50 seeds of rice-grains which were disinfected by dipping them into a 0.1% solution of NaOCl for 20 minutes followed by thorough washing with sterilized water, were put on a filter paper moistened with sterilized water (5~8 ml) in a petri-dish (ϕ 9 cm). The whole system was kept at 30°C for a few days to germinate. Those having 1 cm or more 1 cm length of germ-

sprouting were taken as the complete germination while others were discarded so that the percentage of germination could be obtained. Four germination-tests on the same kind of rice-grains were carried out and their percentages of germination were averaged. This value was taken as the germination-rate.

(10) *Evaluation of the cooking quality of hulled rice-grains.*¹⁵⁾ 8 g of hulled rice-grains and 160 ml of water were mixed in a stainless steel container (ϕ 4.63 cm $\times$ 9.7 cm) and the contents of 4 containers were cooked in a Tatung automatic electric rice-cooker. The cooked rice was kept in the warm position for 15 minutes or more after automatic shut-down of the rice-cooker switch (cooking time: 25 min, except Taichung-46 glutinous rice for 35 min). The cooked rice was assessed for cooking quality after cooling down for 20 min, e.g., measurement of the volume of the cooked rice, water-absorption rate*⁶ and pH value of the rice soup. A sensory evaluation on both the color and flavor of the cooked rice was also performed.

RESULTS AND DISCUSSION

1. *Survivals of microorganisms on gamma-irradiated rice-grains during preservation*

The microorganisms existing on the surface of original rice-grains and their survivals on the gamma-irradiated rice-grains are listed in Table I, in which the results of the preserved rice-grains are also included. The mean values of 3 or 4 replicates are given.

Table I reveals that the microorganisms existing on the rice-grains which were irradiated with a gamma-dose of 100 krad were markedly reduced to below 40% of the original figure. A further sharp reduction on the survivals of microorganisms was found by increasing the gamma-dose up to 2 Mrad due to more complete sterilization. The contaminated microorganisms were also reduced during the six months' storage of the sealed rice-grain bags, whether the rice-grain bags had been gamma-irradiated or not. This is attributed to the shortage of oxygen and moisture in the

*³ Mixed solution: 0.8 ml of NaNO₂ solution (23 g of NaNO₂ in 100 ml of H₂O), 0.8 ml of para-aminoacetophenone solution (2.5 g dissolved in 9 ml of conc. HCl and the solution diluted to 100 ml with water), 10 ml of water and 25 ml of NaOH-NaHCO₃ solution (60 g of NaOH, 84 g of NaHCO₃ in 1 liter aqueous solution) were mixed together.

*⁴ Potato-starch solution: 0.2 g of potato-starch, 0.6 g of KH₂PO₄ and 0.147 g of CaCl₂·2H₂O were together dissolved in 100 ml of sterilized distilled water and the solution boiled for 1 minute.

*⁵ KI-I₂ solution: 6 g of KI and 0.2 g of I₂ were dissolved in 100 ml of distilled water. 1 ml of this stock solution was diluted to 100 ml in volume with 0.05 N HCl and this solution was used.

*⁶ Water-absorption rate: Weight of cooked rice/wt. of original rice.

TABLE I. SURVIVALS OF MICROORGANISMS ON THE IRRADIATED RICE-GRAINS AND AFTER SIX MONTHS' STORAGE

Rice-type	Storage		Survivals of microorganisms (per 100 grains)								
	Time (month)	Temp. (°C)	Gamma-doses (krad)								
			0	10	30	50	100	300	500	1,000	2,000
Taichung-1	0	Room temp.	2.05×10^6 (100)	$1.55 \times 10^{6*}$ (75.61)	$1.05 \times 10^{6*}$ (51.22)	$1.02 \times 10^{6*}$ (49.76)	$8.15 \times 10^{5*}$ (39.76)	$1.65 \times 10^{5*}$ (8.05)	$1.37 \times 10^{5*}$ (6.68)	$1.46 \times 10^{4*}$ (0.71)	$4.60 \times 10^{2*}$ (0.0224)
	6	Room temp.	1.40×10^6 (68.29)	3.20×10^5 (15.61)	2.70×10^5 (13.17)	7.40×10^4 (3.61)	2.03×10^5 (9.90)	1.43×10^5 (6.97)	5.8×10^3 (0.28)	1.90×10^3 (0.0927)	4.00×10^2 (0.0195)
	6	20	1.00×10^6 (48.78)	9.00×10^5 (43.90)	5.00×10^5 (24.4)	3.06×10^5 (14.9)	3.90×10^5 (19.03)	1.90×10^5 (9.27)	1.34×10^4 (0.65)	3.35×10^3 (0.16)	4.80×10^2 (0.0234)
Tainan-5	0	Room temp.	2.09×10^6 (100)	$1.28 \times 10^{6*}$ (61.24)	$8.83 \times 10^{5*}$ (42.25)	$6.7 \times 10^{5*}$ (32.06)	$4.1 \times 10^{5*}$ (19.62)	$1.13 \times 10^{5*}$ (5.41)	$1.82 \times 10^{4*}$ (0.87)	$1.22 \times 10^{4*}$ (0.58)	$2.3 \times 10^{2*}$ (0.011)
	6	Room temp.	1.40×10^6 (66.98)	1.28×10^6 (61.24)	7.86×10^5 (38.34)	2.94×10^5 (14.34)	3.01×10^5 (14.40)	1.27×10^5 (6.08)	2.5×10^4 (1.19)	5.0×10^3 (0.24)	1.6×10^2 (0.0078)
	6	20	1.75×10^6 (83.73)	1.13×10^6 (47.85)	5.0×10^5 (23.92)	5.25×10^5 (25.12)	4.0×10^5 (19.14)	1.38×10^5 (6.60)	1.88×10^4 (0.90)	8.65×10^3 (0.41)	5.6×10^2 (0.0268)
Taichung-46	0	Room temp.	1.1×10^7 (100)	$9.63 \times 10^{6*}$ (87.55)	$8.5 \times 10^{6*}$ (77.27)	$5.5 \times 10^{6*}$ (50.00)	$3.5 \times 10^{6*}$ (31.82)	$1.0 \times 10^{6*}$ (9.09)	$3.2 \times 10^{5*}$ (2.91)	$2.69 \times 10^{4*}$ (0.25)	$1.45 \times 10^{3*}$ (0.0132)
	6	Room temp.	2.0×10^6 (18.18)	1.5×10^6 (13.64)	1.05×10^6 (9.09)	8.8×10^5 (8.00)	5.8×10^5 (5.27)	1.5×10^5 (1.36)	5.25×10^4 (0.48)	1.62×10^4 (0.15)	3.5×10^2 (0.032)
	6	20	4.75×10^6 (43.18)	4.36×10^6 (39.64)	2.77×10^6 (25.18)	1.8×10^6 (18.36)	1.49×10^6 (13.55)	2.9×10^5 (2.55)	1.4×10^5 (1.27)	3.9×10^4 (0.35)	3.52×10^3 (0.032)

* Immediately after gamma-irradiation.

The figures in parenthesis indicate the percentage of the surviving microorganisms and moulds based on the figure of 100 for unirradiated rice-grains.

TABLE II. ANALYTICAL RESULTS OF THE RICE-GRAIN INGREDIENTS DURING STORAGE

Rice-type	Storage		Fatty acids (KOH mg/100 g rice)						Reducing sugars (g/100 g rice)						Thiamine ($\mu\text{g}/10\text{ g rice}$)					
	Time	Tem.	Gamma-doses (krad)						Gamma-doses (krad)						Gamma-doses (krad)					
	(month)	(°C)	0	10	30	50	100	300	0	10	30	50	100	300	0	10	30	50	100	300
Taichung-1	0	Room temp.	39.7	37.9*	32.8*	36.1*	37.0*	37.9*	0.82	0.94*	0.74*	0.76*	0.82	0.82*	93.6	105.8*	105.2*	97.8*	93.9*	98.6*
	6	20	41.1	41.1	41.1	45.3	44.4	45.3	0.69	0.67	0.68	0.67	0.65	0.72	105	94.5	113.4	97.2	87.5	92.0
	6	Room temp.	49.5	39.0	49.5	45.3	45.3	49.5	0.60	0.61	0.58	0.60	0.61	0.65	101.3	91.3	105.6	105.2	90.2	92.6
	12	20	25.7	28.3	24.1	26.7	28.4	22.3	0.64	0.62	0.60	0.62	0.65	0.65	69.5	69.9	74.9	69.9	69.3	72.3
	12	Room temp.	26.7	29.4	31.0	28.3	24.1	26.8	0.59	0.65	0.76	0.62	0.65	0.53	64.2	58.8	65.7	61.1	58.2	64.8
Tainan-5	0	Room temp.	36.1	38.6*	38.8*	37.6*	38.1*	38.1*	0.92	0.83*	0.83*	0.89*	0.90*	0.92*	86.9	82.9*	81.4*	73.9*	77.6*	79.2*
	6	20	41.3	37.3	37.3	39.7	41.2	41.2	0.69	0.64	0.61	0.67	0.64	0.67	99.6	97.2	92.6	90.5	83.4	85.4
	6	Room temp.	43.2	51.2	47.6	43.6	43.2	47.6	0.61	0.69	0.75	0.73	0.75	0.73	107.1	107.4	105.0	117.5	108.8	95.4
	12	20	37.1	34.9	35.5	28.9	30.6	29.5	0.72	0.81	0.79	0.75	0.72	0.74	56.1	57.0	60.9	64.8	71.6	66.0
	12	Room temp.	45.8	39.3	40.4	38.2	41.5	40.9	0.80	0.53	0.66	0.56	0.65	0.71	72.5	60.9	76.8	62.3	62.6	55.2
Taichung-46	0	Room temp.	68.2	72.6*	81.3*	79.3*	78.5*	81.1*	0.64	0.84*	0.73*	0.74*	0.69*	0.69*	51.6	63.4*	59.3*	55.3*	53.4*	49.6*
	6	20	54.5	43.5	53.0	47.0	50.1	47.0	0.67	0.62	0.56	0.54	0.59	0.54	57.9	58.8	55.9	65.0	62.1	67.9
	6	Room temp.	55.0	57.2	50.5	51.4	53.2	65.6	0.63	0.53	0.55	0.51	0.53	0.55	70.5	67.6	75.4	76.5	86.3	82.1
	12	20	46.9	43.6	44.2	45.8	45.3	45.8	0.64	0.85	0.81	0.82	0.83	0.71	67.1	64.0	62.1	60.1	58.5	57.5
	12	Room temp.	50.7	51.8	49.6	49.1	46.9	43.1	0.63	0.76	0.66	0.63	0.72	0.75	72.1	78.8	69.7	73.5	73.2	72.1

* Immediately after gamma-irradiation.

sealed rice-grain bags during storage. No more than a 0.5% by weight increase in the moisture content was observed during the two years preservation test.

2. *Analysis of the rice-grain ingredients*

Since the main rice ingredients in polished rice (60% whiteness) have been recognized to be quite stable against gamma-irradiation,¹⁶⁾ it is implied that such ingredients as fats, oils, starch and protein are accordingly not significantly affected by gamma-irradiation. Furthermore these ingredients are better protected by the rice-hulls than those in the polished rice during storage. Based on this consideration, analytical work on the rice-grain ingredients was focussed on the relatively changeable ingredients of fatty acids and reducing sugars, while the gamma-irradiation effect on thiamine content and α -amylase activity was also investigated. These analytical results are summarized in Table II, in which all data were the means of triplicate experimental results.

The fat acidity of the irradiated Taichung-1 and Tainan-5 rice-grains in Table II was found to be almost level with the corresponding unirradiated ones with gamma-doses below 300 krad, while that of the irradiated Taichung-46 rice-grains was increased by 18.9% with the same gamma-dose. However, this fat acidity level decreased markedly for the Taichung-1 and Taichung-46 rice-grains (29.3~46.9% decrease) during the twelve months preservation test. Under the same conditions, Tainan-5 rice-grains showed a slight increase of fatty acids (7.4%). The twenty four months preservation test revealed that fat acidity was reduced to around 40~45% of the corresponding original rice-grains before the preservation test. Generally, the three kinds of rice-grains were noticed, unlike their polished versions, to be little affected by gamma-irradiation in regard to the formation of fatty acids, and the majority of these fatty acids were reduced considerably after the twelve months preservation test. Complete protection from air oxidation of the fats and oils

in rice-grains by the rice-hulls was confirmed by the analysis of fat acidity. Lack of moisture also enabled the living dried rice-grains to suppress the decay of fats and oils due to attack by microorganisms.

Table II also reveals that no significant fluctuation of reducing sugars was noticed with gamma-doses below 300 krad except for the results obtained at a gamma-dose of 10 krad. As this level of dose there was a 14.6% increase of reducing sugars for Taichung-1 hulled rice and a 31.3% increase for Taichung-46 hulled rice, but this became level with the corresponding unirradiated rice as the gamma-dose was raised to 300 krad. This phenomenon is believed to be due to the excitation of α -amylase in promoting the partial digestion of starch molecules in the rice-grains. The content of reducing sugars was also found to have decreased by 25~38% compared with the corresponding original unirradiated or irradiated rice-grains after the twelve months preservation test for both Taichung-1 and Tainan-5 rice-grains, while Taichung-46 rice-grains showed almost unchanged reducing sugar content during the same preservation period. The twenty four months preservation test showed a continuous decrease of the content of reducing sugars to around 35~40% of the respective original rice-grains whether they were irradiated or not.

The content of thiamine was found to vary slightly with gamma-doses up to 300 krad for all three kinds of rice-grains as shown in Table II. However, after the twelve months preservation test, the content of thiamine decreased by 34~45% (room temp. storage) or 19~29% (20°C storage) for the irradiated Taichung-1 rice-grains and decreased by 31.4% (room temp. storage) or 25.7% (20°C storage) compared with the pre-preserved unirradiated one. Similarly, the irradiated Tainan-5 rice-grains showed a decrease of 5.7~30.3% (room temp. storage) or 7.7~31.2% (20°C storage) decrease and the unirradiated Tainan-5 rice-grains showed a decrease of 16.6% (room temp. storage) or 35.4% (20°C storage). However, the irradiated

Taichung-46 rice-grains gave an increases of 17.5~45.4% (room temp. storage) or 0.9~15.9% (20°C storage), while the unirradiated one gave an increase of 39.7% (room temp. storage) or 30% (20°C storage).

3. α -Amylase activity

The activity of α -amylase in the irradiated rice-grains under the preservation test is shown

in Figs. 1, 2 and 3 in which the means of triplicated test data within a deviation of 2.6% were used for plotting:

From these three figures, it is seen that the activity of α -amylase was enhanced by the gamma-irradiation up to 30 krad and then it was decreased gradually (Taichung-1 and Taichung-46) or sharply (Tainan-5) as the gamma-dose was raised above 30 krad. The

FIG. 1. The Activity of α -Amylase in the Irradiated Taichung-1 Rice-grains during the Preservation Test.

FIG. 2. The Activity of α -Amylase in the Irradiated Tainan-5 Rice-grains during the Preservation Test.

FIG. 3. The Activity of α -Amylase in the Irradiated Taichung-46 Rice-grains during the Preservation Test.

FIG. 4. The Germination-rate vs. the Gamma-dose during Preservation at 20°C.

unirradiated rice-grains gave a much lower α -amylase activity than the respective irradiated rice-grains with a 10 krad gamma-dose, *i.e.*, Taichung-1 was 41% less, Tainan-5 2.9% less and Taichung-46 12.4% less. The preservation-tests revealed that the α -amylase activity in the three irradiated rice-grains decreased considerably with twelve months storage at both room-temperature and 20°C as did the unirradiated rice-grains, *e.g.*, Taichung-1 showing 22% (room temp. storage) and 47.6% (20°C storage), Tainan-5 showing 16.2% (room temp. storage) and 39.1% (20°C storage), while Taichung-46 showed 0.1% (room temp. storage) and 36.8% (20°C storage) less α -amylase content with the corresponding un-

irradiated rice-grains preserved for twelve months. Generally the α -amylase activity declined as the preservation-period was extended and it was also found to be higher at the lower temperature of 20°C than at room temperature.

4. Germination-rate of rice-grains

The germination-rate of the irradiated rice-grains before and after preservation at 20°C for six months and twelve months, is shown in Fig. 4 in which the means of triplicated data were applied for plotting.

It is obvious from Fig. 4 that the irradiated Taichung-1 rice-grains showed the highest germination-rate among the three kinds of

FIG. 5. Cooking Quality of Taichung-1 Rice-grains.

rice-grains, giving the least difference between pre- and the post-preservation at 20°C, while Tainan-5 and Taichung-46 rice-grains showed a lower germination-rate, and a greater difference between pre- and the post-preservation at the same temperature. The germination-rate of the unirradiated and the gamma-irradiated rice-grains was similar up to a 30 krad dose, followed by the sharp decline with gamma-doses over 50 krad. This tendency was recognized to be similar to the decline of α -amylase activity.

5. Evaluation of the cooking quality of rice-grains

Observation of the cooking quality of gamma-irradiated rice-grains was focussed on the color, rice-fragrance, pH-value of the cooked rice-soup and water-absorption or volume of the cooked rice. The cooked hull-ed rice-samples retained their original color and nice fragrance except for Taichung-46 rice irradiated with 300 krad which developed a pale yellow color and slightly disagreeable odor.

The experimental results for the pH-value of

FIG. 6. Cooking Quality of Tainan-5 Rice-grains.

FIG. 7. Cooking Quality of Taichung-46 Rice-grains.

rice-soup, the water-absorption and the volume of the cooked rice for the three kinds of rice-grains which were irradiated with gamma-doses below 300 krad and preserved for six and twelve months, are plotted as shown in Figs. 5, 6 and 7.

The pH-values of rice-soups remained virtually unchanged regardless of the gamma-irradiation at the doses below 300 krad. The preservation-test also showed only small differences in pH value according to preservation time. The water-absorption of the cooked rice revealed some irregularly scattered data. Generally, water absorption was highest after 6 months of preservation and a 30 krad gamma-dose.

6. Deleterious effect of rice-insects

The six months-preserved rice-grains which were unirradiated or irradiated with the gamma-doses below 30 krad all suffered from serious rice-insect damage which degraded the rice-fragrance with cooking. Gamma-irradiation doses over 50 krad was effective for the complete sterilization of the insect-eggs on the surface of rice-grains.

CONCLUSION

The major Taiwan-produced rice-grains such as Taichung-1, Tainan-5 and Taichung-46 rice-grains, have been investigated for the effect of gamma-irradiation. Doses of

100~300 krad were found to extend their storage life to two years or more at room temperature with a relative humidity of 60%.

REFERENCES

- 1) *Scientific Agriculture*, **25**, 113 (1977) (in Chinese).
- 2) F. K. Hsie and S. S. Kao, *Monthly Science*, **7**, 26 (1976) (in Chinese).
- 3) T. J. Lian, T. N. Chen and T. Lin, *Scientific Agriculture*, **2**(8), 34 (1954) (in Chinese).
- 4) H. Iizuka and H. Ito, *Nippon Nôgeikagaku Kaishi*, **4**, 578 (1967) (in Japanese).
- 5) R. C. Nicholas and D. E. Wiant, *Food Technology*, **13**, 58 (1959).
- 6) H. Ito and H. Iizuka, *Food Irradiation*, **4**, 1 (1969) (in Japanese).
- 7) K. Namiki, K. Kurahashi and S. Kawagishi, *Food Irradiation*, **4**, 104 (1969) (in Japanese).
- 8) E. C. Manoto and L. T. Villacarlos, Report of Philippine Atomic Energy Commission III, Feb. 27, 1976.
- 9) FAO/IAEA/WHO, Report of Joint Committee on Wholesomeness of Irradiated Food, 1977.
- 10) H. Ito and H. Iizuka, *Agric. Biol. Chem.*, **35**, 1566 (1971).
- 11) A.O.A.C., 12 Edition, 1975, p. 232.
- 12) T. Kobayashi and T. Tabuchi, *Nippon Nôgeikagaku Kaishi*, **28**, 171 (1954) (in Japanese).
- 13) C. M. Lyman, R. Ory, M. Trant and G. Rich, *Anal. Chem.*, **24**, 1020 (1952).
- 14) N. J. Chrispeel and T. E. Varner, *Plant Physiol.*, **42**, 398 (1967).
- 15) J. F. Williams and M. L. Peterson, *Crop Science*, **13**, 612 (1973).
- 16) U. P. Wang, Y. T. Lai, J. Y. Chang, C. L. Yet and C. Y. Lee, *J. Chinese Agric. Chem. Soc.*, **18**, 1 (1980).