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GERMINATION OF RICE SEED AS AFFECTED BY TEMPERATURE, FUNGICIDES, AND AGE[1]

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INTRODUCTION

The most troublesome weed pest in the California rice fields is water grass (*Echinochloa crus-galli*) and its varieties, which are widely distributed throughout the rice-growing area. These grasses grow well in water and their seed will germinate under water. However, while the rice seedlings stretch to the surface of the water, the grass seedlings are suffocated to a large extent. Taking advantage of this fact, rice growers are now using water to control or check the growth of water grass. The rice is sown broadcast from April 15 to May 20, and the fields are then continuously submerged with water until drained for harvest. At seeding time the temperature of the atmosphere, the soil, and the water used for irrigation usually is too low for maximum germination and rapid growth. Later in the season the temperature of the water and atmosphere may be too high for best results, and some growers have reported that the rice seedlings were "scalded" when germinated under shallow water.

In a study of the effects of temperature and moisture upon the germination of rice seed, Akemine (1, 2)[3] found (a) that the maximum, optimum, and minimum temperatures for the germination of rice are 104°, 86° to 95°, and 50° to 55.4° F.,[4] respectively; (b) that rice germinates equally well in water and in air, whether the grains are hulled or dehulled; (c) that the plumule appears sooner if the seed is placed in the air under favorable moisture conditions than if placed in water, and the radicle and crown roots also develop considerably sooner in the air than in water; (d) that after the plumule appears it grows much more rapidly in water than in air, the opposite being true of the radicle and crown roots; (e) that the frequent renewal of water had no sensible effect upon the development of the plumule, radicle, and roots, the same holding true for differences in

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[3]Reference by number is to "Literature Cited," p. 591.

[4]Data given by Akemine in degrees Centigrade, but for comparison with other data given in this paper they are converted to Fahrenheit.

depth of water, provided limits were between 1.2 to 8 inches; (f) that a suitable degree of moisture for the germination of rice is 60 to 95% by weight of the water-holding capacity of the seedbed; (g) that rice grains are saturated by a quantity of water equal to about 25 to 30% of their air-dry weight; and (h) that rice grains can not be made to germinate until they have absorbed a quantity of water equal to about 25% of their air-dry weight.

Da Fano (3), in experiments with five varieties of rice and three varieties of corn, made a study of the effect upon germination of varying the temperature, of the loss of moisture in the seed during exposure to the various temperatures, and of the percentage of moisture in the seed during germination. The experiment included the incubation of the seed of different varieties for from one to three hours at temperatures of 86°, 104,° 122,° 140°, 158°, 176°, and of 194°F[5]. This seed and the check then were germinated at a laboratory temperature of approximately 73.4°F. The author concludes that in rice the maximum germination was obtained after exposure of the seed for three hours at 86°F., except with the Ranghino variety, which attained its maximum germination after two hours' exposure at 104° F. The percentage of germination of the different varieties varied between 84 and 88%. The minimum germination obtained during three hours incubation at 176° F. varied from 18 to 24%, while incubation for one hour at 194° F. entirely destroyed the power of germination.

Harrington (4) found that rice germinated equally well at the following alternating temperatures:[6]

Approximate maximum temperature	85.1°F.	83.3°F.	91.4°F.	83.3°F.	90.5°F.
Approximate mean temperature	72.5°F.	72.5°F.	75.2°F.	74.3°F.	77.9°F.
Temperature at end of 15 hours	68.0°F.	70.7°F.	71.6°F.	72.1°F.	73.4°F.
Number of hours below 78.5°F.	16	14	12	11	10
Number of hours at 68°F.	12	4	3	3	2

Kondō (5) harvested rice at four stages of development: One, milk; two, yellow ripe; three, fully ripe; and four, dead ripe. When tested for germination, he found that the seed harvested in the milk stage was viable but lacked vigor, although he reports a satisfactory germination after drying. Storage for from one to three months improved the germination of the seed harvested in the yellow ripe stage. The ripe seed germinated well immediately after harvest but im-

[5]Data given by Da Fano in degrees Centigrade, but for comparison with other data given in this paper they are converted to Fahrenheit.

[6]Data given by Harrington in degrees Centigrade, but for comparison with other data given in this paper they are converted to Fahrenheit.

proved in viability with one month's storage. The dead ripe seed germinated very well soon after harvest and showed little improvement with storage. Drying in the sun improved the viability of immature grains, but storage in the panicles was found to be harmful. Seed harvested in the milk stage failed to develop plumules, while other seeds lacked the radicle at times.

Nagai (6) found that rice can be germinated at an extremely low oxygen pressure, but under such conditions the development of the radicle is totally inhibited. A supply of oxygen initiates the development of the radicle in seedlings thus germinated. No appreciable stimulation was observed in the germination of rice seeds as the result of variation of H and OH ions. The germination of rice was practically unaffected by a few hours' exposure to the extremely low temperature of liquid air; two hours' exposure of desiccated rice seed at temperatures of 206.6° to 208.4°F. only slightly affected its germination.

EXPERIMENTAL WORK

In California a considerable rice acreage is sown broadcast and immediately submerged. Information on the germination of rice under water and as affected by different temperature conditions is, therefore, of practical interest. Most of the experiments herein reported were conducted at the University of California in 1923 and 1924.

The purpose in conducting the experiments was to determine, if possible:

1. The effect on the germination of rice seed of long exposure under water to low temperatures compared with short exposure in a moist condition to high temperatures.
2. The effect on the germination of rice seed exposed in a dry condition for a short time to high temperatures.
3. The effect on germination of changeable temperatures compared with constant temperatures.
4. The effect of treatment with fungicides on rice seed germination.
5. The effect of age upon the viability of rice seed.
6. The effect of various seed defects on the germination of rice seed.

EQUIPMENT AND METHODS

In the experiment on exposure to low temperatures seed was placed in Petri dishes and submerged in water. The Petri dishes were then placed in refrigeration rooms which were maintained at practically

constant temperatures. At the end of the period of exposure the water was changed on the seeds and they were placed under room temperature (60° to 80° F.) to germinate.

In the experiments on exposure to high temperatures and germination at constant temperatures, two electric ovens were used. One oven was constructed of zinc-lined wood and the other of asbestos with wire shelves. Each oven was equipped with a thermostat for temperature control. Standard Fahrenheit thermometers were used. It was not possible to adjust the thermostats to maintain a constant uniform tempertaure during the 24-hour day, and the oven temperatures varied from 2° to 4° F., when set for a given temperature.

The seed exposed in a moist condition was placed in Petri dishes, the bottoms of which had been covered with several layers of paper toweling. More than enough water was added to each Petri dish to saturate the paper. These containers were convenient, and excellent germination was obtained when the rice was placed on the saturated paper toweling and covered. The seed exposed in a dry condition was placed in clean dry Petri dishes.

Each sample consisted of either 50 or 100 seeds, and in several of the experiments duplicate samples were used. In some of the experiments the seed was germinated after exposure in a standard germinator with temperature control, while in others the germination was at room temperatures.

Eight varieties of rice were used in certain experiments; in others only one or two varieties were used. They included Caloro, Wataribune, Shinriki, Colusa, Eureka, Butte, Early Prolific, and Honduras. Colusa and Eureka are early maturing, Caloro and Butte are mid-season, and Wataribune and Shinriki are late-maturing, short-grain rices. Early Prolific is a medium-grain variety, and Honduras a long-grain variety. Well-matured, recleaned seed from the Biggs Rice Field Station, of the Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture, Biggs, Claif., was used in the experiments, the only exception being the Shinriki seed which was slightly immature.

EXPOSURE EXPERIMENTS WITH RICE SEED

1. EXPOSURE FOR A LONG PERIOD TO LOW TEMPERATURE

In these experiments the rice was placed in Petri dishes and submerged in water, or inclosed in saturated "rag dolls." The Petri dishes and "rag dolls" were then placed in refrigeration rooms at constant temperatures of 32°, 36°, and 40°F. The length of exposure

TABLE 1.—*Germination percentages of rice seed after exposure under water for 20 days at 36° and 40° F., and for 36 days at 32°, 36°, and 40° F., with notes on the character of resulting plantlets.*

Variety	Number of seeds	Germination percentages and growth									
		Exposed 20 days						Exposed 36 days			
		36°F.		40°F.		32°F.		36°F.		40°F.	
		Per cent	Character	Per cent	Character	Per cent	Character	Per cent	Character	Per cent	Character
Colusa	100	95	V.[b]	98	V.			77	V.	97	V.
Eureka	100	78	F.	96	V.V.			61	V.	81	V.
Caloro	100	25	W.	70	W.	15	W.	15	P.	53	P.
Butte	100	84	V.	85	V.V.			57	F.	57	P.
Wataribune	100	95	V.	99	V.V.			82	V.	94	V.
Shinriki	100	8	V.W.	23	V.W.			00	—	2	V.W.
Early Prolific	100	85	V.W.	98	F.			73	P.	98	F.V.
Honduras	100	8	V.W.	25	V.W.			5	V.P.	23	V.W.
Caloro—Control[a]	100	79	V.V.	92	V.V.	97	V.	97	V.V.	90	V.
Caloro in "rag doll"	100	57	V.V.	62	V.V.	8	W.	17	V.V.	45	V.V.

[a]Not exposed at low temperatures.

[b]Symbols in columns headed "Character" signify the following: V.V. = very vigorous; V. = vigorous; F.V. = fairly vigorous; F. = fair; P. = poor; W. = weak; and V.W. = very weak.

is indicated in Table 1. At the end of the period of exposure the samples were removed to a room in which the temperatures varied from 60° to 90° F. Fresh water was added to the Petri dishes and the "rag dolls" were again saturated with fresh water. All seed, except that in the "rag dolls," was germinated under water in the Petri dishes. The results obtained in these experiments are presented in Table 1.

During exposure at 32°F. the "rag doll" was frozen solid, but no ice formed in the Petri dish. While no actual weight tests were made, the rice seed did not appear to absorb water very readily at low temperatures.

After exposure at 36° F. for 20 days, the Colusa, Wataribune, Early Prolific, and Butte varieties showed a comparatively high percentage of germination, whereas the germination of the remaining varieties appeared to have been materially reduced. The percentage germination of all varieties was higher after exposure for 20 days at 40° than at 36° F., and the same varieties, Colusa, Wataribune, and Early Prolific, had a slightly higher percentage of germination than did the Caloro control. The average germination of the five control lots in these experiments was 91%.

The germinating power of Caloro seed was greatly reduced by exposure for 36 days at 32°F. The vitality of the seed was less affected under water than in a "rag doll."

The percentage germination of all varieties was higher after exposure at 36° and 40° F., respectively, for 20 days than for 36 days, except for Early Prolific, which had the same percentage germination in both tests. In three of the five experiments the percentage germination of Caloro seed after exposure was higher in Petri dishes than in "rag dolls," and in both containers the germination was decidedly lower after exposure than for the unexposed seed.

These results indicate that Colusa, Wataribune, and Early Prolific are more resistant to the detrimental effects of long exposure under water than are the other varieties used in these experiments. The poor germination of Shinriki no doubt was partly the result of using slightly immature seed. This indicates that well-matured rice seed is more resistant to adverse conditions than immature seed.

During the exposure period more or less fungous growth developed on the seeds, and this may have affected germination. However, in some instances the percentage of germination was high in spite of the considerable fungous contamination.

2. EXPOSURE FOR A SHORT TIME TO HIGH TEMPERATURES

In this experiment Caloro seed was placed in Petri dishes and submerged in water. Different samples were exposed daily for two,

four, six, and eight hours, respectively, to a temperature which varied from 100° to 118°F., the average during the experiment being 110°F. When not exposed to heat the seed was kept at room temperature, 60° to 80° F. This test was started March 6 and continued until March 12. The results obtained are given in Table 2.

The percentage of germination was materially decreased by exposure for eight hours each 24-hour day, but exposure for two, four, and six hours each day appeared to stimulate and, possibly, slightly to increase germination.

TABLE 2.—*Effect on the germination of different lots of Caloro rice seed under water exposed each day until germinated to a high temperature for two, four, six, and eight hours, respectively.*

Lot number	Number of seeds	Number of hours exposed	Germination March 8 %	Germination March 12 %	Remarks
2	100	2	15	87	Vigorous seedlings
4	100	4	6	83	Vigorous seedlings
6	100	6	4	87	Vigorous seedlings
8	100	8	0	58	Fairly vigorous
1	100	0	0	82	Vigorous seedlings
7	100	0	0	83	Vigorous seedlings

3. EXPOSURE FOR ONE, TWO, AND THREE HOURS, RESPECTIVELY, TO HIGH TMEPERATURES

Duplicate samples of Colusa and Caloro rice seed were used in this experiment. The seed was placed on saturated paper toweling in Petri dishes and exposed for one, two, and three hours, respectively, to constant temperatures of 122°, 130°, and 152°F. An unexposed control and the exposed seed were germinated at a constant temperature of 86°F. The results obtained in this experiment are presented in Table 3.

TABLE 3.—*Effect on germination of exposing rice seed in a moist condition for a short time to high temperatures.*

Variety	Number of seeds	Percentage germination and temperature and length of exposure: 122°F. 1 hr.	122°F. 2 hrs.	130°F. 1 hr.	130°F. 2 hrs.	152°F. 1 hr.	152°F. 2 hrs.	152°F. 3 hrs.	152°F.[a] 1 hr.	152°F.[a] 2 hrs.	152°F.[a] 3 hrs.	Control, not exposed
Colusa.....	100	98	98	95	92	40	11	0	0	0	0	98
Colusa.....	100	98	—	93	97	79	0	0	0	0	0	100
Caloro.....	100	97	96	99	72	90	0	0	0	0	0	98
Caloro.....	100	99	—	95	87	88	4	0	0	0	0	98

[a]Exposed on two successive days.

The results show that exposure at 122° and 130° F. for one or two hours had no appreciable effect on germination. Exposure for two

hours at 130°F. appears to have reduced the percentage germination of the Caloro seed. Exposure for one hour at 152°F. materially reduced the percentage germination of both varieties; two hours' exposure to 152°F. practically destroyed the power of germination of both varieties; and three hours' exposure entirely destroyed the power of germination of both varieties. Either one, two, or three hours' exposure to 152° F. on two successive days destroyed the germination power of all seed.

4. EXPOSURE IN A DRY CONDITION TO HIGH TEMPERATURES

In these experiments the seed was placed in clean, dry Petri dishes and exposed for one hour. The exposed seed and the controls were then placed in Petri dishes, in which were several layers of water-saturated paper toweling, and germinated at a constant temperature of about 86° F. The results of these experiments are presented in Table 4.

TABLE 4.—*Percentage of germination of air-dried rice seed after exposure for one hour to high temperatures.*

Variety	Number of seeds	Percentage of germination at 122° F.	130° F.	140° F.	150° F.	158° F.	170° F.	190° F.	205° F.	212° F.	Control
Colusa	100	98	98	100	98	89	94	68	0	0	99
Colusa	100	98	98	100	100	53[a]	97	27	0	0	98
Caloro	100	99	96	98	96	97	55[a]	4	0	0	99
Caloro	100	98	98	97	97	99	90	5	0	0	98

[a]Rice began to ferment—possibly reason for low value.

The results indicate that exposure for one hour at 122°, 130°, 140°, 150°, and 158° F. apparently did not reduce the germination of either variety. One hour's exposure at 170°F. appeared to reduce the germination of the Caloro variety. At 190° F. the percentage germination of both varieties was greatly reduced. The Caloro seed was injured to a greater extent than the Colusa seed. At 205° and 212°F. one hour of exposure killed all seed of both varieties.

These experiments, when compared with those in which the seed was exposed in a wet condition, show very clearly that air-dried rice seed will stand a much higher temperature than wet seed without affecting its germination.

GERMINATION AT VARYING TEMPERATURES

Seed of eight varieties of rice submerged in Petri dishes was placed on a window sill with a southern exposure. During the period of germination the maximum temperature varied from 58° to 117°F., and the minimum temperature from 42° to 50°F.

Seed of the same varieties submerged in Petri dishes was placed in a room which remained comparatively constant in temperature, varying only from 65° to 71° F. during the germination period. The results obtained in these tests are presented in Table 5. The percentage of germination of the different varieties on the window sill varied from 70% for Shinriki to 100% for Colusa and Eureka. At this range in temperature all the varieties, except Shinriki and Honduras, showed a high percentage of germination. At the lower temperature (56° to 71° F.) the germination was satisfactory but not quite so high as that at the higher temperature. However, five of the eight varieties used showed a germination above 90%.

TABLE 5.—*Percentage of germination and vigor of seedlings of eight varieties of rice germinated under widely varying and under rather constant temperatures.*

Variety	Number of seeds	42° to 117°F. Germination[a] %	42° to 117°F. Seedling vigor	65° to 71°F. Germination[a] %	65° to 71°F. Seedling vigor
In Petri dishes					
Colusa	100	100	Vigorous	98	Vigorous
Eureka	100	100	Vigorous	98	Vigorous
Caloro	100	95	Vigorous	83	Poor
Butte	100	97	Fair	95	Vigorous
Wataribune	100	100	Very vigorous	100	Vigorous
Shinriki	100	70	Fair	80	Vigorous
Early Prolific	100	99	Fairly vigorous	98	Very vigorous
Honduras	100	75	Weak	68	Weak
In "rag doll"					
Caloro	100	88	Very weak	91	Very weak

[a]Average percentage of duplicate lots of 100 seeds.

Under like conditions some rice varieties germinate much more quickly than others. Germination proceeds much more rapidly at high temperatures than at low temperatures.

These experiments indicate that rice may be expected to germinate well at a comparatively constant temperature, if above 65°F., or at a daily range in temperature which may vary from 42° to 117°F.

GERMINATION AT CONSTANT TEMPERATURES

The preceding data show that rice germinates very well at daily variations in temperature from 42° to 117°F., or from 65° to 71°F. during the period of germination. To determine its germination at constant temperatures rice seed was germinated on saturated paper toweling in Petri dishes at constant temperatures. The results of these experiments are presented in Table 6.

The data show that at a constant temperature of 61°, 68°, 86°, 88°, 93°, and 100°F. the germination for both rice varieties used was

above 93% in all cases. At a constant temperature of 108°F. all Colusa seed was killed and only a few seeds of Caloro germinated. At a constant temperature of 122°F. the seed of both varieties was so injured by the heat that no germination was recorded.

TABLE 6.—*Percentage of germination of rice seed at constant temperatures.*

Variety	Number of seeds	Percentage of germination							
		61°F.	68°F.	86°F.	88°F.	93°F.	100°F.	108°F.	122°F.
Colusa	100	93	96	97	100	98	98	0	0
Colusa	100	94	96	95	97	99	100	0	0
Caloro	100	97	93	96	99	96	95	11	0
Caloro	100	95	94	98	97	96	97	4	0

These results indicate that rice does not require an alteration in temperature in order to germinate well, and that at the constant temperatures used the germination of both varieties was excellent. However, at a low temperature, that is, about 61°F., germination was rather slow. The germination period at 61°F. extended from March 25 to April 9, while at 93°F. the seed was practically all germinated in five days.

EFFECT OF TREATMENT WITH FUNGICIDES ON THE GERMINATION OF RICE SEED

1. FUNGICIDAL TREATMENT AND GERMINATION IN PETRI DISHES AND "RAG DOLLS"

In some of the preceding experiments, especially those in which the seeds were exposed to low temperatures or germinated at low temperatures, fungi often developed on the seeds before germination. In some cases it was thought that possibly the fungi reduced the percentage of germination. On the other hand, seed badly infected with fungi often germinated well. At the suggestion of Prof. W. W. Mackie, Cerealist of the California Experiment Station, some seed was treated with fungicides before being prepared for germination.

In the first experiment samples of seed were treated as follows: (a) Dusted with copper carbonate; (b) dusted with copper sulfate; (c) soaked for one hour in a 1 to 400 solution of uspulun; and (d) untreated. Each lot of seed was submerged in water in Petri dishes at the time the uspulun lot was set to soak, so that all lots received water at the same time.

In the second experiment duplicate lots of seed were treated as follows: (a) Dusted with copper carbonate; (b) soaked for one and one-half hours in a 1 to 40 solution of copper sulfate; (c) soaked for one and one-half hours in a 1 to 400 solution of uspulun; and (d) untreated. The seeds after treatment were germinated, one part of

each lot under water in Petri dishes and a second part in moist "rag dolls."

The results of the seed treatment experiments are presented in Table 7. Treatment with copper sulfate dust was very injurious and reduced the percentage of germination. Treatment with either copper carbonate dust or uspulun appeared slightly to stimulate early germination in some cases, but the data are not consistent enough to prove general stimulation. In one series of the second experiment the germination of the rice seed in "rag dolls" apparently was decreased by treatment with either copper sulfate or uspulun. In the Petri dishes the percentage of germination was about the same for treated and untreated seed. In the second series of the second experiment there was little difference in the percentage of germination in Petri dishes and in "rag dolls" for either treated or untreated seed.

In these experiments on seed treatment it was observed that the seeds were practically free of fungi and early germination seemed to be stimulated in some cases.

TABLE 7.—*Effect of treatment with fungicides upon the germination of Caloro rice seed.*

Seed treatment	First experiment		Second experiment, Series 1		Second experiment, Series 2	
	Germination[a]	Length of seedling in mm.	Germination	Length of seedling in mm.	Germination	Character
	%		%		%	
In Petri dishes						
None	90	15	97	10–20	92	Vigorous
Copper carbonate dust.	95	5	96	3–12	93	Vigorous
Copper sulfate solution	18[b]	1	98	3–12	94	Vigorous
Uspulun solution	91	5	98	10–20	95	Vigorous
In "rag dolls"						
None			97	1–10	96	Vigorous
Copper carbonate dust.			99	1–12	96	Vigorous
Copper sulfate solution			88	1–7	91	Vigorous
Uspulun solution			89	1–7	98	Vigorous

[a]Each lot consisted of 100 seeds.

[b]Copper sulfate dust used.

2. SEED TREATMENT AND GERMINATION UNDER FIELD CONDITIONS

On May 6, 1923, three lots of Caloro rice seed were soaked for one to two hours as follows: (a) In water; (b) in a 1 to 40 solution of copper sulfate; and (c) in a 1 to 400 solution of uspulun. Part of the seed from the lot soaked in water was later thoroughly dusted with copper carbonate. After treatment six systematically replicated rod rows of each seed lot were sown in the nursery on well-prepared land.

The rows were spaced 3 feet apart and the seed spaced 3 inches apart in the rows, making 66 seeds sown in each row. All seed was carefully covered after hand sowing.

The land was irrigated and drained on May 7. After the first irrigation the land was irrigated and drained at intervals of about eight days until the rice emerged.

Careful observations were made during germination and emergence of the rice, but no stimulating effect was noted from seed treatment. In fact, the seed treated with copper carbonate was considerably slower in emerging than the untreated seed or the seed treated with copper sulfate or with uspulun. Examination of some of the seeds dusted with copper carbonate, which failed to emerge, showed that they had germinated but the seedling had failed to grow. This probably indicated that after germination the copper carbonate had a toxic effect on the seedlings.

The results secured in this experiment are presented in Table 8. The stands obtained in the replicated rows for the same treatment varied considerably. Thus, the number of seedlings that emerged, based on the number of seeds sown, for the untreated rows ranged from 27.3 to 48.5%, or a variation amounting to 43.7% of the maximum. The copper carbonate rows ranged in emergence from 34.9 to 53%, the copper sulfate rows from 50 to 68.2%, and the uspulun rows from 41 to 53%. While the results show that more plants emerged from treated seed than from untreated seed, it seems doubtful whether seed treatment actually increased the stand. The increase probably should not be attributed entirely to seed treatment, since other factors probably were involved.

TABLE 8.—*Effect of treatment with fungicides upon the field germination of Caloro rice seed.*

Row No.	Untreated		Copper carbonate		Copper sulfate		Uspulun	
	Number of seedlings emerged	Percentage of emergence	Number of seedlings emerged	Percentage of emergence	Number of seedlings emerged	Percentage of emergence	Number of seedlings emerged	Percentage of emergence
1	24	36.7	23	34.9	36	54.6	30	45.5
2	23	34.9	27	41.0	44	66.7	35	53.0
3	32	48.5	30	45.5	44	66.7	27	41.0
4	24	36.4	35	53.0	45	68.2	34	51.5
5	18	27.3	30	45.5	33	50.0	34	51.5
6	24	36.4	34	51.5	40	60.6	34	51.5
Total	145	—	179	—	242	—	194	—
Average percentage of emergence		36.7		45.2		61.1		49.0

EFFECT OF AGE UPON THE VITALITY OF RICE SEED

1. EFFECT OF LONGEVITY UPON THE GERMINATION OF RICE SEED

There is little information regarding the effect of age on the germination of rice seed. This question is of interest to rice growers as well as to those engaged in experimentation and breeding. Crop failure, or loss of the crop as the result of unfavorable weather conditions, or fire, may make it necessary to use old seed in planting the next crop. Information regarding the germination of old seed, therefore, is of interest.

Eight varieties of rice, the seed of which varied in age from one to six years, were used in this test. The seeds, 100 in each lot, were germinated under water. During the germination period the average maximum temperature was 93.2°F., and the average minimum temperature 72.5°F. The results obtained in this experiment are presented in Table 9.

TABLE 9.—*Germination percentages of rice seed of eight varieties, ranging in age from one to six years.*

Seed Year grown	Age in years	Germination percentages Colusa	Caloro	Watari-bune	Fukuyama	Omachi	Butte	Carolina White	Honduras
1917	6	31	3	4	75	0	—	—	—
1918	5	85	45	41	86	5	—	—	—
1919	4	64	20	19	86	12	53	54	22
1920	3	85	19	24	98	72	98	96	99
1921	2	99	61	93	100	100	99	100	99
1922	1	100	99	99	100	99	98	98	99

The data indicate that some rice varieties deteriorate more rapidly with age than others. Seed of Fukuyama and Colusa four, five, and six years old germinated much better than did seed of Wataribune, Omachi, and Caloro. It appears probable that some factor other than age affected the germination of seed harvested in 1919. This seed may have been slightly immature. From the data it appears that rice seed stored in a dry condition should give a relatively high germination until three years old. Seed stored for a longer time is likely to be decidedly low in vitality.

2. EFFECT OF STAGE OF MATURITY ON THE GERMINATION OF RICE SEED

In September and October, 1923, seed of three varieties of rice was harvested at five different stages of development; the milk, dough, hard dough, first ripe, and dead ripe. When harvested the panicles were placed in manila paper bags and kept in a dry condition until used for germination tests in January, 1924. Triplicate lots of 50

seeds each for all stages of development were germinated between moist sheets of blotting paper at a constant temperature of 82°F. The lots were germinated at the same time in one large container so that all samples were germinated under like conditions of temperature, moisture, etc. The period of germination was from January 29 to February 9. The results obtained are presented in Table 10.

TABLE 10.—*Effect of stage of maturity on the germination of rice seed.*

Stage of maturity	Percentage of germination: Individual lots: Colusa	Watari-bune	Early Prolific	Average: Colusa	Watari-bune	Early Prolific	Average for the three varieties
Milk stage	0	10	4				
Milk stage	0	16	6				
Milk stage	0	18	8	0	15	6	7
Dough stage	36	82	60				
Dough stage	48	66	86				
Dough stage	70	28	80	51	59	75	62
Hard dough stage	74	64	50				
Hard dough stage	80	66	70				
Hard dough stage	76	70	64	77	67	61	68
First ripe	90	86	98				
First ripe	88	96	98				
First ripe	92	90	98	90	91	98	93
Dead ripe	96	100	100				
Dead ripe	98	96	98				
Dead ripe	98	100	98	97	99	99	98
Field threshed	100	98	100				
Field threshed	96	96	98				
Field threshed	98	100	98	98	98	99	98

There was no germination of the Colusa seed harvested in the milk stage. The Wataribune and Early Prolific seed harvested at this stage germinated, although very poorly. There was a marked increase in germination in all varieties with each successive stage of development from the milk to the dead ripe stages. A minor variation from this tendency occurred with Early Prolific, which gave about the same germination for the seed harvested in the first ripe and dead ripe stages. Field-threshed seed and dead ripe seed germinated about the same.

The results show that the ability of rice seed to germinate increases with each successive stage of maturity.

GERMINATION OF NORMAL AND DEFECTIVE RICE SEED

The use of rice seed which is not well matured, or which contains brown-hulled kernels, dehulled kernels, dehulled half-kernels, etc., is not recommended but may be necessary in certain cases. The value

of such seed when sown is, therefore, of practical interest. Caloro rice seed of each of these defective groups was prepared in 100-seed lots and was germinated between sheets of moist blotting paper. The temperature during the period of germination varied from 55° to 102°F., the greatest daily range being 41°F. The results of this experiment are presented in Table 11.

TABLE 11.—*Percentages of germination of well-matured, immature, brown-hulled, and dehulled kernels, and hulled and dehulled half-kernels of rice.*

Variety	Number of seeds	Condition of seed	Germination
			%
Caloro	100	Well matured	96
Caloro	100	Immature	67
Caloro	100	Brown-hulled	92
Caloro	100	Dehulled	86
Caloro	100	Hulled half-kernel	95
Caloro	100	Dehulled half-kernel	100

The germination for the different lots varied from 67% for the immature seed to 100% for the dehulled half-kernels containing germs. The temperature apparently was ideal for germination in this test. Under field conditions at the usual date and rate of seeding the percentage germination for all lots probably would have been much lower than those here reported. The results show, however, that under favorable conditions brown-hulled and dehulled kernels, and hulled and dehulled half-kernels containing germs can be used for seed, if necessary.

SUMMARY

The results of these experiments indicate:

1. Seeds of some rice varieties are more resistant to deterioration during long exposure under water at low temperatures than those of other varieties. Colusa, Wataribune, and Early Prolific appear to be the most resistant of the varieties used in these experiments.

2. An exposure of eight hours under water at 100° to 118°F. in each 24-hour day greatly reduced the germination of Caloro seed, while two, four, and six hours' exposure each day did not noticeably affect germination.

3. The exposure of moist rice seed for one and two hours at 122° and 130°F. had no appreciable effect on germination. An exposure for one hour at 152°F. materially reduced the germination of seed of both the Caloro and Colusa varieties. A two-hour exposure practically killed all seed of both varieties, and a three-hour exposure entirely killed all seed of both varieties.

4. An exposure of dry rice seed for one hour at 122°, 130°, 140°,

150°, and 158°F. did not affect germination. A one-hour exposure at 170°F., appeared to reduce the germination of Caloro seed. A one-hour exposure at 190°F. greatly reduced the germination of both Caloro and Colusa rice, and at 205°F. all seed was killed.

5. Rice seed germinated very well when subjected to a range in temperature from 42° to 117°F., or from 65° to 71°F. during the period of germination. Some varieties germinate more quickly than others and all varieties germinate quicker at high than at low temperatures.

6. Rice seed germinated about equally well at constant temperatures of about 61°, 68°, 86°, 88°, 93°, and 100°F. At 108°F. no seeds of Colusa, and only a few seeds of the Caloro variety, germinated. At 122°F. all seeds of both varieties were killed.

7. Seed treatment with copper carbonate dust, a 1 to 40 solution of copper sulfate, or a 1 to 400 solution of uspulun prevented the growth of fungi, and in some cases appeared to stimulate the germination of rice seed submerged in Petri dishes.

8. Seed treatment with the above fungicides resulted in better stands under field conditions, but the increased stand may have resulted from other factors than seed treatment. Copper carbonate appeared to be toxic to some seedlings after germination.

9. The seeds of some rice varieties appear to deteriorate with age faster than others. Three-year-old seed of five varieties tested ranged in germination from 85 to 99%, while the other three varieties in the test ranged in germination from 19 to 72%. The vitality of rice seed more than three years old is likely to be low.

10. The percentage of germination of rice seed, harvested at different stages of development, increased with increased maturity from the milk to the dead ripe stages.

11. Brown-hulled and dehulled kernels and dehulled and hulled half-kernels of rice germinate well under favorable conditions. Immature seed usually is low in vitality.

LITERATURE CITED

1. AKEMINE, M. Zur Kenntnis der Keimungsphysiologie von *Oryza sativa* (Reis). *In* Fühling's Landw. Ztg., Jahrg., 63: Heft 3, 78–93. 1914.
2. ———. Beitrag zur Kenntnis der Keimung von *Oryza sativa*. *In* Osterr. Bot. Ztschr., Jahrg., 63: No. 5, 194–200. 1913.
3. DA FANO, A. Sulla germinabilità del riso (*Oryza sativa*) e del granturco (*Zea mays*) in rapporto alla temperatura ed alla umidità. *In* Atti 1st. Bot. R. Univ. Pavia, Ser. 2, 16:17–39. 1916.
4. HARRINGTON, G. T. Use of alternating temperatures in the germination of seeds. *In* Jour. Agr. Res., 23:295–332, figs. 1–20. 1923.

5. KONDŌ, M. Über Nachreife und Keimung verschieden reifer Reiskörner (*Oryza sativa* L.). *In* Ber. Ohara Inst. Landw. Forsch., 1:361–387. 1918.
6. NAGAI, I. Some studies on the germination of the seed of *Oryza sativa*. *In* Jour. Col. Agr., Imp. Univ. Tokyo, 3:109–158, pl. 9, figs. 1–2. 1916.