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EFFECTS OF HEAT TREATMENT ON THE VIABILITY OF RICE A REPORT OF RESEARCH
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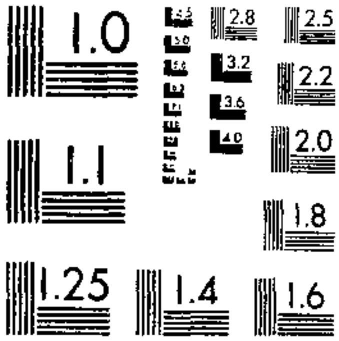

MICROCOPY RESOLUTION TEST CHART
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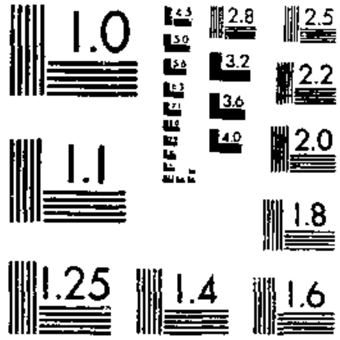

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Effects of Heat Treatment on the Viability of Rice

A Report of Research and a Literature Survey

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CONTENTS

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Effects of Heat Treatment on the Viability of Rice

A Report of Research and a Literature Survey [1]

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INTRODUCTION

The effects of heat on rough, or paddy, rice (*Oryza sativa*) have assumed greater importance in the United States since the introduction of combine harvesting and the associated need for artificial drying, or conditioning. Improvements in the method of drying, including equipment and operation, are limited by the danger of heat injury to the rice. Practical rice-drying procedures have been developed largely as a result of experimentation in commercial plants. Fortuitously, procedures that have favored high milling yields have generally favored high seed viability. Nevertheless, they present sizable risks if we consider, for example, that in 1952 over 48 million centals of rice were produced in Arkansas, Louisiana, Texas, Mississippi, and California (*67*)[3]. Most of this rice was combined at moisture contents above 14 percent and required artificial drying before milling or storage.

Very little is known about the effects of heat alone on the viability of artificially dried rough rice, on the activity of its enzymes, on the nutritional availability or destruction of its proteins and vitamins, or on its other characteristics and constituents. Much of the knowledge now applied in the heat treatment of rough rice is based on the assumption that its behavior will be analogous to that observed for other seeds that have been similarly heat-treated.

To advance our knowledge of the effects of heat on rice, a series of investigations were undertaken during the harvesting seasons of 1950, 1951, and 1952. Representative experiments are reported in this bulletin. Their scope is limited primarily to demonstrating certain temperature, time, and moisture-content relationships of treatment to the viability of rough rice.

The authors decided to investigate the effects of the different variables on viability rather than on other physical, chemical, or biological

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[2] The authors are indebted to W. G. Taggart, director (retired) of the Louisiana Agricultural Experiment Station; to H. T. Barr, head of the Agricultural Engineering Research Department; and to R. K. Walker, superintendent, and L. G. Coonrod, formerly assistant agricultural engineer, of the Rice Experiment Station, for the privilege of conducting the heat-treatment experiments at the Rice Experiment Station, Crowley, La.

[3] Italic numbers in parentheses refer to Literature Cited, p. 47.

characteristics. There were practical reasons for this decision. The samples of heat-treated rough rice were too small for satisfactory milling-evaluation tests. To obtain larger samples would have necessitated decreasing the number of variables investigated. Skilled technical assistants were not available to perform complicated biochemical tests. On the other hand, facilities were adequate for making germination tests. Moreover, these tests reflect the biological conditions of seeds within limitations. They have the added advantage of being universally used and understood. Hence, they provide data interpretable by many workers other than seed analysts, such as seedsmen and farmers, commercial grain-drier operators and millers, plant physiologists and pathologists, and biochemists.

Although three major variables—temperature of treatment, time (duration) of treatment, and moisture content of the rice—are considered, the greatest emphasis is placed on the temperature of treatment, or the heat. This is because artificially heated air is used in the commercial drying, or conditioning, of rough rice and because it has been useful in preventing deterioration of rice during storage.

Experiments were planned to accomplish several objectives. Chief among them were to determine (1) the effect of temperature of heating on viability, (2) the effect of time (duration) of heating on viability, (3) the relationship between the moisture content of the rough rice and the temperature of heating and its effect on viability, and (4) the effect of prolonged storage on the viability of heat-treated rice.

SOUTHERN PRACTICES IN RICE CONDITIONING

Changes in the methods of harvesting and storing are responsible for the present interest in the effects of heat on rice. Approximately 90 percent of the South's annual rice crop is now combined, according to Jones *et al.* (*41*). Smith and Jones (*76*) found that the best time to harvest rice is ". . . when the moisture content of the standing rice ranges from about 23 to 28 percent." McNeal (*59*) and Sorenson *et al.* (*78*) in recent studies reported that rice should be combined when its moisture content is within the 16- to 26-percent range, i. e., if the field losses, including shelling and breakage in the combine, are to be reduced to a minimum and if maximum yields of rough and head rice are to be obtained. Freshly combined rough rice will deteriorate rapidly unless promptly dried, or conditioned.

Artificially heated air is used in commercial dehydration operations to reduce the moisture content of the freshly combined rough rice to 14 percent, but the attainment of this moisture level is no guarantee that the rice will keep indefinitely under all conditions of storage (Sorenson *et al.* *78*). The reason is that high temperatures and humidities prevail in the southern rice-growing areas—Louisiana, Texas, Arkansas, and Mississippi (Jenkins *35* and Kramer *50*). Significant contributions have been made to the knowledge of rice drying, or conditioning, as it is practiced in the United States (Smith *et al.* *72*, *73*, *74*, *75*, *76*; Bodnar *13*; Barger *et al.* *11*; Engler and McNeal *29*; McNeal *56*, *57*, *58*, *60*; Aldred and Kramer *3*, *4*; Kramer *46*, *47*, *48*, *49*; Kramer and Aldred *51*; Slusher and Mullins *70*, *71*; Sorenson *et al.*

77, 78; the Louisiana Agricultural Experiment Station *54*; Cruz and Laforteza *20*; Bond *14*; and Autrey *et al.* *8*).

Bin aeration and drying techniques are being developed to remove the excess moisture from rough rice that has been stored at too high a moisture content, that has absorbed moisture since storage, or that is heating. Ambient air is commonly used during the warm daylight hours when the relative humidity is low. Artificially heated air is used if the need for the rapid removal of moisture is apparent. Several workers have contributed articles on the development of bin aeration and drying techniques. Among them are Stirniman *et al.* (*79*), Todd (*83*), Barr and Coonrod (*12*), Coonrod (*16*), Sorenson *et al.* (*78*), and Morrison *et al.* (*63, 64*), and the Louisiana Agricultural Experiment Station (*55*).

Rice for seed is often dried in commercial drying units in the same manner as the bulk that is dried to a moisture content suitable for milling or storage. The commercial units are, of course, cleaned and inspected before being loaded with rice to be dried for seed purposes. Their use is largely one of convenience. Germination tests and farm-crop observations support the practice, but data are not available to evaluate present commercial drying procedures from the standpoint of improving seed quality.

REVIEW OF LITERATURE

Although heat has probably been applied in the treatment of rough rice for centuries, there are but few published accounts—at least those readily available to occidental readers—that describe its effect on the ability of rice to germinate. On the other hand, a number of publications, a few of which have appeared in recent years, present data on the effect of heat treatment on germination capacity, but mostly for other kinds of seed than rice.

Da Fano (*21*) investigated the influence of time and temperature of heating on varieties of rice and corn. Lots of each variety of rice were exposed to ambient temperatures and to 30°–90° C. at 10° intervals for 1, 2, and 3 hours. Moisture contents of the samples appeared to have been within a 13- to 15-percent range prior to treatment, except two ambient-air-dried controls, which were 18.62 and 21.2 percent, respectively. After treatment the moisture contents ranged from 4.3 to 12.93 percent and the moisture losses from 1.18 to 9.11 percent. Germination tests were made immediately after treatment. Vialone nero and Chinese rice varieties demonstrated maximum ability to germinate after heating at 30° for 3 hours, the Ranghino variety after heating at 40° for 2 hours. Minimum germinating abilities were constantly obtained by heating at 80° for 3 hours, and the seed germinating ranged between 18 and 24 percent. All the varieties lost their germinating power completely when heated at 90° for 1 hour. The investigator did not find the maximum germinating power to correspond to the maximum percentage of water contained in the seeds put to germinate. She did find, however, that heat treatments within favorable time and temperature ranges improved the germination capacity of the treated over that of the ambient-air-dried rice. She also recognized the possible significance of the pretreatment history of the seed in affecting the experimental results.

Nagai (*65*) exposed air-dried and desiccated grains of rice for 2 hours at 97°–98° C. He found that the germinative power of the grain, especially if desiccated, was only slightly affected.

Jones (*39*) exposed Colusa and Caloro rice seed on saturated paper toweling in petri dishes for 1, 2, and 3 hours, respectively, at constant temperatures of 50°, 54.4°, and 66.7° C. Exposure for 1 to 2 hours at 50° and 54.4° had no appreciable effect on germination capacity, but exposure at 66.7° for 1 hour materially reduced the percentage germination of both varieties, and exposure for 3 hours entirely destroyed the power of germination.

In another series of experiments Jones exposed air-dried seed of the same two varieties in clean, dry petri dishes for 1 hour at 50°, 54.4°, 60°, 65.6°, 70°, 76.7°, 87.8°, 96.1°, and 100° C. Treatment at 70° or under apparently did not reduce the germination of either variety. The 76.7° treatment slightly reduced the germination capacity of the Caloro variety. An 87.8° treatment greatly reduced the germination capacities of both varieties, that of the Caloro to a greater extent than that of the Colusa. Treatments at 96.1° and 100° for 1 hour killed all seed of both varieties. Jones stated that these experiments show that air-dried seed will stand a much higher temperature than wet seed and its germination will not be affected.

Further interpretation of the data and observations of Da Fano, Nagai, and Jones is not attempted, because each failed to describe clearly and completely the experimental conditions employed. In Da Fano's experiments the rice lost moisture during heat treatment. In Jones' experiments the moist rice probably did not lose an appreciable amount. On the other hand, Jones did not give the moisture contents of his lots of rice either before or after treatment.

Smith *et al.* (*74*) in their study of the effect of date of harvest on yield and milling quality of rice were the first to remark on the effect of germination of the artificial drying of rice in an experimental and in a commercial drier. Germination tests were made on samples of Blue Rose rice dried in the laboratory under normal air conditions and in the experimental drier at DeWitt, Ark., with the air at 43.3°, 48.9°, 54.4°, and 60° C. Results of similar tests made on samples of Early Prolific, Fortuna, and Blue Rose rice dried in the experimental drier at Nome, Tex., gave no indication of injury resulting from artificial drying at the temperatures used. Additional tests made in a greenhouse on some of the samples of rice gave no clear evidence of any difference in the seedlings from the samples dried at different temperatures. Samples were obtained from a lot of seed rice dried with a commercial drier with the air at approximately 48.9°, and no indication was found of injury to germination resulting from the drying operation.

Sorenson *et al.* (*77*) dried sacks containing approximately a barrel each of rough rice in a tunnel-type sack drier at air temperatures of 46.1°, 51.7°, 65.6°, 79.4°, and 93.3° C., respectively, to determine the effect of the drying air temperature and the initial moisture content of the grain on the milling quality and the germination. Sacks of rice of 24-percent, of 20- to 21-percent, and of 17-percent moisture content were dried at each temperature, except the last was not dried at 93.3°. Drying times were longer at the lower temperatures. The temperature of the air in the rice during drying and the moisture content of the rice on completion of drying were generally lower in the center of the sack than at the top and bottom. When injury to germination capacity occurred, it was greater in the top and bottom layers than in the center of the sack. Too high an air temperature had a detrimental effect on both the germination and the milling quality of rice. A temperature of 65.6° had no detrimental effect on germination for rice with 17–21 percent of moisture. These workers advised that the air temperature, however, should not exceed 51.7° to 54.4° for rice with 24 percent of moisture. The temperature of the rice with either moisture content was considerably lower than the drying air temperature owing to the cooling effect of evaporation.

McNeal (*58*) in 1944, 1945, and 1946 conducted a series of studies on the artificial drying of combined rice to obtain information on the relation of such factors as times dried, air temperature, relative humidity, and drying time to milling results and germination. Rice varieties (Zenith, Kamrose, Jap-type, Fortuna, Nira, and Prelude) were harvested at a moisture content of 20–24 percent, and stored and tempered 6 to 12 hours in barrels prior to drying. Twelve-pound samples of each tempered variety were dried in experimental driers. "One, two, three, and sometimes four dryings were used to reduce the moisture content of the rice from field condition to 14 percent. . . ." The tempering period between succeeding dryings was generally 24 hours. Drying temperatures ranged in intervals of 5.5° C. from 37.8° to 87.8°, but not all rice varieties were dried at each temperature. Extremes in total drying times ranged from 15 minutes at 87.8° to 220 minutes at 37.8°. Total drying time usually decreased as the number of dryings was increased. An important conclusion of the studies was that germination is reduced when rice is dried at air temperatures above 54.4°. Some of the data indicated that there might be varietal differences in resistance to heat and that at the higher temperatures intermittent drying might be less destructive of germination capacity than continuous drying.

Aldred and Kramer (*3*) and Kramer (*49*) dried samples, one grain thick, of Caloro, Zenith, Bluebonnet, Magnolia, and Rexoro at temperatures from 32.2° to 61.1° C. A loss in germination usually occurred at temperatures above 43.3° C., and fast rates of drying did not appear to reduce germination.

Later Aldred and Kramer (*4*) made a study ". . . to obtain comparative milling and germination results on the same lot of rice dried simultaneously in two identical Berico driers with all drying conditions held constant except drying air temperature." The rice was exposed for 15 minutes to an average air temperature of 46.1° or 51.9° C. and to an air volume of about 500 cubic feet per minute per barrel. Additional dryings were sometimes necessary. Dried samples were seasoned for 30 days before milling tests and 60 days before germination tests. No significant difference was noted in the milling qualities of the rice dried at the two temperatures. Usually an increase in germination resulted at the higher temperature.

In the preceding studies (Smith *et al.*, Sorenson *et al.*, McNeal, and Aldred and Kramer) the rice was exposed to different temperatures of artificially heated air. Although the heated air may be maintained at a constant temperature for a definite period, no data are available as to the maximum temperature reached by the grains of rice or as to the time they are maintained at this temperature. The data supplied by these workers do not define the tolerance of rice to a given temperature in itself. Nevertheless they do permit an estimation of the effect on germination capacity when rice is exposed to a given temperature during drying in present-day commercial dehydration equipment.

In contrast to the preceding investigations, in which there is doubt about the temperatures reached by the rice, Adair and Cralley (*1*) presoaked rice seed for 12 hours and then immersed it in hot water at 50°–52° C. for 15 minutes. This treatment effectively controlled white tip in 19 varieties of rice, and although not indicated apparently did not have an adverse effect on the germination capacity of the seed.

Tisdale (*82*) found that soaking Louisiana Honduras rice in water at 54° C. for 15 minutes after presoaking it for 16 hours killed the internal fungi and came nearest to giving as good germination as the untreated controls. However, in practically every experiment with presoaked rice the germination was slightly lower than that of the untreated controls.

Tisdale did not give the initial moisture content of the rice, but it is interesting to note in one of his experiments that when the time and temperature of the hot-water treatment remained constant the germination capacity was lower the longer the period of the presoak. This observation suggests that the differences in the germination capacities of the different batches of treated seed probably reflect differences in the degree of resistance to heat as related to differences in presoaking times and moisture contents at the time of exposure.

As the preceding review indicates the literature concerned with the effect of temperature on germinating ability of rice consists, for the most part, of a heterogeneous collection of studies. The more systematic studies have been concerned with correlating limited air-drying temperature, air-drying time, and seed-moisture relationships with milling quality and germination capacity. Even these leave much to be desired because they were limited in scope and the temperatures of the lots of seed being dried were not determined. No one has reported investigations in which lots of rice of different moisture contents but of the same variety and from the same field plot have been exposed to different temperatures for different periods of time.

Waggoner (*87*) is probably the first to have studied ". . . in series, the resistance of the same kind of seeds containing definite and known quantities of water at the time of heating." He has tabulated germination data for radish seeds having initial percent moisture contents of 4, 9, 14, 18, 23, 30, 38, 45, 50, and 71, and which have been exposed for 30 minutes in single layers in submerged Florence flasks at temperatures from 50° to 100° C. at 5° intervals. Other data are also given for radish seeds of lower moisture contents, for higher temperatures of heating (to 125°), and for different methods of heating. His conclusions, which are particularly noteworthy, are as follows:

> The resistance of seeds of *Raphinus* [sic] *sativus* L. exposed to high temperatures is inversely proportional to the initial water content of the seeds at the time of heating.
>
> At temperatures high enough to be injurious the viability of radish seeds of a given initial water content decreases as the temperature to which they are subjected is raised.
>
> The general resistance of Icicle, Black Spanish Winter and Crystal Forcing radish seeds exposed to high temperatures is very similar.

Radish seeds injured by high water content and high temperatures are retarded in their germination. This retardation becomes more marked as the temperature or water content or both is increased.

Radish seeds of the same initial water content show very great differences in resistance when heated at the same temperature but by different methods, namely: in water, in dry corked flasks, or in open dishes in ovens.

The amount of water absorbed or given off by radish seeds during treatment is the chief factor determining the resistance of the seeds heated at the same temperature by the different methods.

When radish seeds are heated directly in water they suffer a gradual loss of dry substance. This loss becomes greater as the temperature of the water is increased.

Hutchinson's experiments (*33*) executed 28 years later with wheat of the Square Heads Master variety possess refinements over those of Waggoner. Samples of wheat with moisture contents ranging from 3.2 to 35 percent were heated for intervals of 12, 24, 36, 48, 60, and 120 minutes at temperatures ranging from 44° to 116° C. The standard heating period for the more extensive work was 60 minutes. In treatment 15-mm. diameter tubes of glass or brass were packed one-third full, closed, and submerged in a bath of the desired temperature for a specified period of time. Germination tests were normally made on the treated seed after it had had a 24-hour rest period. Some of the highlights of Hutchinson's findings are:

1. Excessive heat-treatment is characterized by (*a*) death in some of the grains, (*b*) those not killed showing varying delays in germination as compared with the controls. This germination lag, which as yet cannot be eliminated, must be considered as a sign of damage. . . .

2. There are two stages of damage due to heating: (*a*) where the lag is small but definite, increasing rapidly with temperature, and (*b*) where the lag is great and the slightest increase in the temperature completely destroys germination capacity. . . .

When the temperatures at which these two stages occurred were plotted by Hutchinson for the moisture content of each of the 3.2- to 35-percent moisture samples, he obtained two curves.

The upper curve at each time interval shows the minimum temperatures at each moisture content for which the germination capacity after treatment is nil, whilst the lower curve shows the temperatures at which the first stage of damage occurs, i. e., where there is a definite delay in germination, although germination capacity as such is scarcely affected. . . . For any given period of heat-treatment the area between the two curves can be regarded as the "zone of heat damage."

*　　*　　*　　*　　*　　*　　*

3. . . . in the range of moisture content, 35% to 11%, the upper and lower boundaries of the damage zone could be defined in the form of the two equations: upper, *i. e.*, nil germination: $\theta = 130 \cdot 3 - 5 \cdot 4 \log_e t - 43 \cdot 87 \log_e m$; lower, *i. e.*, start of damage: $\theta = 122 \cdot 0 - 5 \cdot 4 \log_e t - 43 \cdot 87 \times \log_e m$, where θ is the temperature in °C., t is the time of exposure in minutes (corrected to allow for the time taken to reach this temperature), m is the % moisture content of the wheat. These equations apply to the range 8 minutes to 116 minutes and are given because they may possibly be of value in connexion with the conditions in commercial dryers.

4. Heat exerted its destructive action on the germination capacity of wheat of a given moisture content over a relatively short temperature range. This range for the 60 minute heat-treatment curves extending from "start of damage" to "nil germination" remained about the same in magnitude (8° to 12°), but differed in its position on the temperature scale for wheat of each moisture content. Hutchinson

referred to this narrow critical temperature range as being about 9° C. (Hutchinson *et al. 34*).

Although the excellent researches of Waggoner and of Hutchinson have not been concerned with rice, they have been cited for the following reasons: (1) They illustrate the kind of research that needed to be undertaken with rice; (2) they have served as patterns in planning the rice research described in this bulletin; and (3) they have resulted in the accumulation of extensive data on the effects of heat treatment on the germination capacities of radish and wheat seed, which are likely to have much in common with those accumulated for rice, in spite of the chemical, structural, and physiological differences in the kinds of seeds and in spite of differences in the experimental procedures.

EXPERIMENTAL MATERIALS AND PROCEDURES

All the rice used in the 1950, 1951, and 1952 experiments was grown in the vicinity of Crowley, La. Varieties, grain types, dates of harvest, and other information are given in table 1.

TABLE 1.—*Data on varieties of rough rice used in heat-treatment experiments, 1950–52*

Year and variety	Grain type	Date combined and heat treatments started	Moisture content of rice [1]	Lot designation (SRRL) [2]
1950				
			Percent	
Sel. 61-25 12	Medium	Sept. 28	25. 1	[3] BR2.
Rexoro	Long	Oct. 2	24. 3	R1.
Zenith	Medium	Oct. 5	21. 5	Z2.
Rexoro	Long	Oct. 16	24. 9	R3.
1951				
Bluebonnet	Long	Sept. 7	25. 2	BB1.
Do	do	Oct. 2	17. 9	BB5.
Sel. 61-25 12	Medium	Oct. 8	19. 8	[3] BR23.
1952				
Bluebonnet	Long	[3]	21. 6	BB10.
Century 52	do	Sept. 30	18. 2	C2.

[1] At time the first samples were taken for heat treatment, usually 1 to 3 hours from time of combining, wet basis.
[2] Southern Regional Research Laboratory.
[3] Combined Sept. 9; heat treatments started Sept. 11.

To assure proximity to a supply of freshly combined rough rice (paddy) of known history, heat-treatment apparatus was set up each season in one of the buildings of the Rice Experiment Station in Crowley. Usually it was possible to obtain a barrel or two of rice from the hopper of a rice cart within 1 to 3 hours of combining. More attention was given to selecting a lot of rice of the highest moisture content available than to choosing a lot of a specific variety. Gross debris, such as sticks, straw, grasshoppers, and weed seed, was removed by hand. No mechanical cleaning of the rough rice was attempted in 1950 and 1951, but one lot was mechanically cleaned in 1952. As soon as a sufficient quantity of a given lot of rice had been cleaned, 100 to 150 heat-resistant glass test tubes, 16 by 150 mm., were tightly packed with rice by jarring the butts against the palm of the hand. These filled and stoppered test tubes were promptly subjected to heat treatment.

While the test tubes were being filled, moisture determinations were being made on five well-mixed portions of the bulk lot of cleaned rice. Their average moisture content was recorded as that of the rice being tubed. On completion of the dispensing, the remainder of the rice was spread in layers to air-dry. It was frequently mixed and checked for moisture content. Each time the moisture content of the lot dropped about 2 percent, a number of test tubes were filled with this rice and heat-treated. This procedure permitted a series of experiments to be run with batches of rice of successively lower natural-moisture contents originating from the same combined lot.

When the weather was warm and dry, a 2-percent drop in moisture content sometimes occurred in 2 or 3 hours, whereas during humid weather it might be delayed several days or until there was a decrease in the relative humidity. With the former condition it was sometimes necessary to hold a batch of rice in a closed container until it could be treated. Holding periods were usually short, 1 to 3 hours, and very rarely exceeded 24 hours unless the rice was dry, that is, 14-percent moisture content or lower. Moisture contents of 9 percent and lower were obtained by drying rice of 10- to 11-percent moisture content in desiccators over calcium chloride and/or phosphorus pentoxide. The control sample, representative of each lot, was always air-dried.

NATURE OF EXPERIMENTS

Two kinds of experiments were undertaken each year. In one, the temperature of heating and the moisture content of the rough rice were the major variables and the time (duration) of treatment was held constant. In the other, the temperature and time of treatment were the major variables and the moisture content of the rice was held constant.

In the experiments with temperature and moisture content as variables, batches of rough rice from the same combined lot but of different moisture contents were separately dispensed, and 10 to 14 test tubes of each were submerged and heat-treated for 30 minutes after the rice reached the temperature of the bath. A 30-minute heating period was selected for most of the experiments because it approached the time rough rice is exposed to high temperatures in commercial driers. Sets of 10 to 14 test tubes of rough rice of the same moisture content and from the same initial batch of rice were each heated at different temperatures.

In the experiments with temperature and time as variables, baskets of filled, stoppered test tubes containing rice of the same moisture content and from the same initial batch of rice were submerged in a water bath at a given temperature. After the contents of the test tubes had reached the temperature of the bath, 3 to 10 test tubes were withdrawn every 10 minutes for periods of 60 to 120 minutes. This procedure was repeated for each of 4 temperatures spaced at 5° intervals in 1950 and 1951 and for each of 7 temperatures spaced at 3° intervals in 1952.

In all experiments whenever a set of completely submerged test tubes was removed from a given bath, the surfaces of the test tubes were quickly dried and the contents were composited in a small absorbent paper tray consisting of four thicknesses of paper toweling. Rice from leaky test tubes and from test tubes fitted with thermocouples was discarded. A moisture determination was made when the composited sample weighed 75 gm. or more (contents of 8 to 14 test tubes). It was made within 2 to 5 minutes of emptying the test tubes, depending upon the number of test tubes and the location of the moisture tester. Immediately after the moisture determination was made, the rice was spread in the tray and placed in a sheltered location to air-dry at the prevailing atmospheric temperature. When dry—14-percent moisture content or lower—the rice was emptied from the tray into a small coded paper bag.

At the conclusion of the field work each season these bags of treated samples and controls were forwarded to the Southern Regional Research Laboratory, New Orleans, La., and stored at 24°–26° C. Germination tests were run on each sample 8, 16, 24, and 32 weeks after the date of treatment.

DETERMINATION OF MOISTURE CONTENT

The moisture content of the rough rice in the range of 10 to 30 percent was determined with a Steinlite Moisture Tester.[4] This instrument was convenient to use in the field and was calibrated each season against the forced-draft oven method for determining the moisture content in the higher range. Samples believed to contain less than 10 percent of moisture were sealed in test tubes and returned to the Southern Regional Research Laboratory, where their respective moisture contents were determined by a forced-draft oven method. In this method the samples were heated at 101° C. for 16 hours in a forced-draft oven, reweighed, and the loss in weight was calculated as moisture content on the wet basis. Samples of 10- to 12-percent moisture content were sometimes similarly checked. All moisture contents were reported on a wet basis and on cleaned seed.

DETERMINATION OF RICE TEMPERATURE DURING HEAT TREATMENT

The temperature of the rough rice in the closed test tubes and the time taken for it to reach the temperature of the bath were determined by means of thermocouples. In each of two test tubes per bath an iron-constantan thermocouple was pushed centrally into the packed rice for 1 to 1½ inches. Each thermocouple lead extended above the water through a long glass tube, which was fitted into a rubber stop-

[4] The mention of trade products or companies does not imply that they are endorsed by the U. S. Department of Agriculture over similar products or companies not mentioned.

per. Leads from the test tubes in the different baths were connected to a multiple switch and this, in turn, to a potentiometer. Potentiometer readings were converted to temperature readings by means of a chart.

WATER BATHS

All the water baths were of homemade construction. Nine plain cylindrical heat-resistant jars, 12 by 12 inches, were each insulated, sides and bottom, with one-fourth-inch sheet asbestos. They were placed on one-half-inch insulation board on a specially constructed combination platform and rack. Accessory equipment compactly arranged at the back of each bath consisted of a relay, mounting bracket, two flexible immersion heaters, a bimetallic thermoregulator, a thermometer, and a stirrer with pulley mounted at the top of its shaft. Stirrer pulleys connected in series to a speed-reducer pulley and driven by an electric motor permitted uniform and continuous agitation of the water in all baths. A set of six water baths is shown in figure 1.

FIGURE 1.—A series of the water baths used in the heat treatment of rough rice.

Test tubes of rice to be submerged were placed in test-tube baskets of noncorrosive wire, each of which was provided with an elongated hook for attachment to the edge of the bath. Each bath was almost covered during operation by a one-fourth-inch compressed-board cover.

DETERMINATION OF PRESSURES IN STOPPERED TUBES

Simultaneously with each heat-treatment experiment in 1952 manometric measurements were made of the total pressures developed in a test tube of rough rice in each bath. The pressure-measuring device consisted of an open-end manometer, one end of which was fitted into a rice-filled test tube by means of a rubber stopper. Each manometer was equipped with a mercury reservoir and a leveling tube, which permitted a constant volume to be maintained during a heating experiment.

A typical experiment consisted in filling the test tube carefully, tightly packing the rice, fitting the manometer in the test tube by means of the rubber stopper, and then submerging the test tube in the water bath. Just prior to submergence of the test tube, however, the mercury leveling tube was adjusted to bring the enclosed system to constant volume, and the initial pressure was recorded. During the course of an experiment in which 8 minutes were allowed for the test tube and contents to attain the temperature of the bath and 30 minutes for the action of heat of a given temperature, the manometer was open to the rice at all times, and was adjusted so as to maintain a constant volume in the enclosed system. The total pressures resulting from the expansion of free air and the vapor were recorded every 5 minutes of the 30-minute period in terms of centimeters of mercury.

GERMINATION TESTS

Seed germination tests were conducted by the method prescribed by the Federal Seed Act (*5, 85*). Four hundred seeds from each sample were germinated in replicates of 100 between layers of moist paper toweling. They were germinated 14 days in the dark in a "water-curtain" type germinator that was automatically and thermostatically controlled. It was set to operate at alternating temperatures of 20° C. for 8 hours and 30° for 16 hours. Counts were made on each sample on the 5th, 7th, 10th, and 14th days. A germinating seed was counted only if it had both a root and a shoot and only if one of these structures was at least one-fourth inch long. Germinated seeds were discarded at the time of counting.

The terms "germination capacity" and "germination vigor" are used throughout the bulletin to refer to total germination and rate of germination, respectively.

HEAT-TREATMENT EXPERIMENTS IN 1950

The investigations in 1950 were started without a priori knowledge of the effects of heat on the viability of rough rice when heat was applied according to the experimental conditions described. Hence, in the experiments in which temperature and moisture content were the major variables, all samples were heat-treated in 5° steps, arbitrarily selected, over a range of 45° to 75° C. Similarly, in the experiments in which temperature and time of heating were the major variables, temperatures of 40°, 45°, 50°, and 55° were also arbitrarily selected.

Three varieties of rice were used in the experiments—Sel. 61–25–12, Rexoro, and Zenith (table 1). Sel. 61–25–12 is a variety developed at the Rice Experiment Station, Crowley, La. (Jodon and De La Houssaye *38*).

Data from representative experiments are given in tables 2–5. The percentages of seed germinating are given only for samples tested 32 weeks from the date of heat treatment. One reason for this partial presentation of data is that no appreciable differences were observed in the germination capacities of seed between the 8- and 32-week periods of storage (24°–26° C.).

TABLE 2.—*Germination of rough rice after heat treatment at different temperatures, 1950*

SEL. 61-25-12

Moisture content (percent)	Duration of heat treatment	Control	45° C.	50° C.	55° C.	60° C.	65° C.	70° C.	75° C.
	Minutes	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
25.1	30	89	89	88	79	0	0	0	0
	60		90	92	76	0	0	0	0
21.7	30	87	87	89	90	82	4	---	---
	60		---	92	88	---	---	0	0
19.5	30	88	89	91	88	87	9	0	0
	60		89	91	90	86	1	0	0
16.2	30	91	91	91	87	90	82	1	0
	60		92	88	87	90	77	0	0
11.7	30	90	91	90	94	89	86	70	0
	60		89	90	87	89	87	39	0
9.4	30	90	88	87	89	92	88	83	0
	60		89	87	88	90	88	71	0
7.4	30	90	88	89	91	85	87	87	90
	60		88	86	90	85	87	87	84
3.8	30	89	86	82	85	85	81	88	85
3.5	60		82	84	87	86	87	87	88

REXORO[1]

Moisture content (percent)	Duration of heat treatment	Control	45° C.	50° C.	55° C.	60° C.	65° C.	70° C.	75° C.
24.3	30	90	87	79	86	62	0	0	0
	60		88	88	86	57	0	0	0
18.6	30	85	89	92	89	87	86	1	0
	60		89	88	89	89	73	0	0
13.2	30	85	89	88	90	91	89	79	0
	60		89	87	87	86	88	76	0
11.1	30	91	87	86	87	88	88	74	1
	60		90	---	88	---	80	---	0

ZENITH

Moisture content (percent)	Duration of heat treatment	Control	45° C.	50° C.	55° C.	60° C.	65° C.	70° C.	75° C.
21.5	30	90	92	92	92	85	33	0	0
16.3	30	92	85	93	91	91	92	36	0
10.6	30	93	91	92	92	92	84	78	0

[1] Lot R1.

TABLE 3.—*Moisture contents of Sel. 61-25-12 rough rice 3 to 5 minutes after heat treatment at different temperatures, 1950*

Moisture content before heat treatment (percent)	Duration of heat treatment	45° C.	50° C.	55° C.	60° C.	65° C.	70° C.	75° C.
	Minutes	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
25.1	30							
	60	24.1	24.2	23.3	25.1	24.1	22.9	23.0
21.7	30	21.4	21.4	21.2	20.9	21.0	20.4	20.3
	60	21.2	21.1	20.5	21.0	20.5	20.7	20.0
19.5	30	19.3	19.0	18.9	19.5	19.5	19.0	18.1
	60	19.0	19.1	19.3	19.8	18.9	18.7	
16.2	30	16.3	16.6	16.2	16.0	16.1	15.8	15.1
	60	15.3	15.9	16.1	15.5	15.7	15.2	15.3
11.7	30	12.4	12.2	12.1	11.9	12.8	11.6	11.6
	60	11.8	11.9	11.8	11.8	11.8	11.7	11.6
9.4	30	9.0	9.2	9.2	8.6	9.0	8.4	8.8
	60	9.3	9.0	9.1	8.9	8.8	8.7	8.4
7.4	30	7.6	7.0	7.3	7.3	7.2	6.7	6.2
	60	7.1	7.3	7.6	6.6	7.1	6.5	6.6
3.8	30		3.9		3.9		3.7	3.7
3.5	60		3.6		3.4	3.4	3.2	3.4

TABLE 4.—*Germination of Rexoro[1] rough rice after heat treatment for different periods of time, 1950*

Temperature of treatment (° C.)	Control	10 min.	20 min.	30 min.	40 min.	50 min.	60 min.	90 min.	120 min.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
40	95	95	95	94	94	94	93	93	93
45		95	92	94	94	96	93	91	95
50	94	94	92	94	93	93	95	94	87
55		94	93	91	90	92	93	88	85

[1] Lot R3.

TABLE 5.—*Effect of time (duration) of heat treatment at 55° C. on the germination of Rexoro[1] rough rice after 5, 7, 10, and 14 days, 1950*

Duration of heat treatment (minutes)	5 days	7 days	10 days	14 days	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Control	91	2	1	0	94
10	75	16	2	1	94
20	68	21	4	0	93
30	64	19	6	2	91
40	63	23	3	1	90
50	46	36	9	1	92
60	51	35	5	2	93
90	40	37	10	1	88
120	37	36	10	2	85

[1] Lot R3.

TEMPERATURE AND MOISTURE-CONTENT VARIABLES

Table 2 shows that as the moisture content in rice decreases its resistance to the destructive action of heat increases. In rough rice of 25- to 26-percent moisture content. viability was completely destroyed in 30 minutes at 60° C. At 3.5- to 7.4-percent moisture content, there was no indication that germination capacity (total germination) had been significantly affected even after 60 minutes at 75°.

Samples with 3.5- to 3.8-percent moisture content exhibited slightly less germination vigor (rate of germination) throughout the study. This loss in vigor was not obvious from the total counts made on the fifth day of the germination test. but it was indicated by shorter roots and shoots than those possessed by the control. Also at this stage the roots were frequently more developed than the shoots.

Table 2 further shows that the range over which heat exerts its destructive action on rice of a given moisture content during exposures of 30 and 60 minutes is a narrow one—about 8°–12° C. This range remains about the same, but its position differs on the temperature scale for rice of each moisture content.

Sel. 61–25–12, Rexoro. and Zenith of corresponding moisture contents displayed about the same degree of resistance to heat. They may differ in their resistance to heat. but these experiments are not considered adequate to establish this variable. Moreover. soil and other environmental variables were not established. The seed of each variety was lacking slightly in uniformity as shown by the germination tests for individual samples of the air-dried controls. A number of tests were made on the air-dried controls at intervals of 8. 16, 24. and 32 weeks. The viability count (percentages) for Sel. 61–25–12 for these intervals averaged 88.7, 88.8. 88.5. and 89.3. respectively: for Rexoro 83.3, 85.4, 87.1. and 87.7: and for Zenith 90, 92.6, 92.7, and 91.6.

Stoppering the test tubes of rice reduced moisture losses during the period of heating. Moisture contents of several samples of Sel. 61–25–12 determined shortly after heat treatment are given in table 3. The data are typical of those obtained throughout the season. Greatest losses occurred from those samples that originally had the highest moisture contents and also from those that had been exposed to the highest temperatures. The greatest loss undoubtedly occurred when the warm rice was exposed to the atmosphere. Usually 3 to 5 minutes elapsed during the emptying, mixing, weighing. and moisture meter reading of a sample. As might be expected samples initially containing from 3.5 to 3.8 percent of moisture lost very little. if any, moisture during this period. The moisture-content values recorded after heat treatment serve only to show that there could not have been much change in moisture content of the rice in the test tubes during heat treatment. They do not reflect the moisture equilibrium conditions within the closed test tubes, the variations in pressure. and such changes as the redistribution of the moisture within a given seed and between seeds in the mass.

TEMPERATURE AND TIME VARIABLES

When samples of Rexoro of 24.9-percent moisture content were heat-treated for periods of 10 to 120 minutes. they all exhibited about the same germination capacity except the two samples heat-treated for 120 minutes at 50° and 55° C., respectively. Table 4 indicates that 10 to 120 minutes of heating at 40°, 45°, 50°, and 55°, with the exceptions noted, did not affect the germination capacity of the rice.

However, on the basis of germination vigor, heat damage was more extensive than is shown in table 4. All samples heat-treated at 55° C. were retarded in their rate of germination (table 5). One sample of the lot heat-treated for 120 minutes at 50° also exhibited a germination lag.

Data similar to those given in tables 4 and 5 were also obtained with Zenith (lot Z3) and Rexoro (lot R5) at moisture contents of 16 and 21.6 percent, respectively. The highest temperature, 55° C., used in the 1950 time-temperature studies brought about some impairment of the germination vigor (table 5), particularly in the samples exposed for 90 and 120 minutes. In general, the treated samples on testing did not satisfactorily illustrate a progressive decrease in germination capacity with increasing temperature and time of treatment (table 4). They did illustrate that rice of a given moisture content could withstand prolonged heating (to 120 minutes) at some temperatures without loss in germination capacity and even without loss in germination vigor. They further illustrated that loss of germination vigor is a more sensitive measure of heat damage than loss of germination capacity. In other words, decreases in germination vigor may be detected at lower temperatures than decreases in germination capacity.

Additional partial confirmation of the time-temperature data are contained in table 2. In this table it is evident that a 60-minute heat-treatment period did not exert any greater detrimental activity on germination capacity than a 30-minute period except when the exposure was at a temperature that fell within the narrow range damaging to rice of a given moisture content.

HEAT-TREATMENT EXPERIMENTS IN 1951

Since verification of the 1950 findings was desired, the experiments in 1951 were similar to those of the preceding year. Two major experiments were planned in greater detail to demonstrate the effects of temperature of heating on the viability of rice of different moisture contents and of time of heating on rice of a given moisture content. In addition, a third experiment was planned to show the effects of heat treatment on the viability of rice of different maturities.

Minor changes were made in the 1950 procedures. The intervals between temperatures of treatment were decreased from 5° to 3° C. Nine samples of each batch of rough rice of a given moisture content were treated instead of seven as in the preceding year (table 2). The overall temperature range was selected on the basis of the moisture content of the rice, and for most batches, except the driest, amounted to 25°. Therefore, the lower the moisture content of the rice, the higher its temperatures (25° range) of treatment. As an illustration, Bluebonnet (lot BB1) with a moisture content of 25.2 percent was heat-treated at temperatures of 46°–70°, with 17.6 percent at 55°–79°, and with 10.7 percent at 61°–85°.

An endeavor was made to select temperatures of treatment for rice of each moisture content so that the lower temperatures would not have any effect on viability, whereas the higher ones would bring about its destruction. These changes to a "sliding temperature scale" and 3° intervals of treatment were made in the hope that the results would permit a closer approximation of the temperatures at which destruction of germination (viability) just started and at which it was just complete.

All test tubes of rough rice were allowed 8 minutes to reach the temperature of the bath. It was observed in following the potentiometer readings in the previous season's experiments that the time for the rice in the test tubes to reach the temperatures of their respective baths did not vary greatly for the different temperatures investigated. Moreover, the germination test data in tables 2 and 4 indicated that 2 or 3 minutes under or in excess of the true time would probably not have any appreciable effect on germinability.

Bluebonnet and Sel. 6I–25–12 were used in the 1951 experiments (table 1). The Bluebonnet is one of the early releases of the Rice-Pasture Experiment Station, Beaumont, Tex., and is referred to locally as the "old style." Table 1 does not list the small lots of rough rice used in the maturity study. They were hand-harvested from September 18 through October 6. Two large bundles of grain were cut from the same field plot each day between 7:15 and 8:15 a. m. Six to eight pounds of rice were promptly stripped from the panicles. Surface moisture, when present, was removed by evaporation. The rough rice was spread in shallow layers in trays with wire-screen bottoms and allowed to air-dry with frequent turning. As soon as the surface moisture had disappeared and the rice was "free flowing," it was tubed and heat-treated. The bundles of rice cut on September 18–28 were from a flooded field. Drainage started the 28th, but the selected plot remained muddy to slightly muddy through October 2. On October 3–6 the soil was still damp but firm.

Moisture contents of the different samples of rough rice, times and temperatures of heat treatment, and germination test data for the 1951 experiments are given in tables 6–11.

TEMPERATURE AND MOISTURE-CONTENT VARIABLES

The percentages of Bluebonnet rough rice germinating 8, 16, 24, and 32 weeks after heat treatment are given in table 6. Data are not recorded for all the samples treated at the higher temperatures that showed zero germination. The variations in the results follow the trends obtained in 1950 for similar experiments.

TABLE 6.—*Germination of Bluebonnet[1] rough rice 8, 16, 24, and 32 weeks after heat treatment for 30 minutes at different temperatures, 1951*

Moisture content (percent)	Control	46° C.	49° C.	52° C.	55° C.	58° C.	61° C.	64° C.	67° C.	70° C.	73° C.	76° C.	79° C.	82° C.	85° C.	88° C.
						8 WEEKS										
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
25.2	84	90	84	75	74	54	<1	0								
23.4	89	89	79	71	72	77	11	0								
20.3			88	87	78	72	73	18	0							
17.6	87				89	88	75	68	68	0	0					
16.4					88	86	88	77	76	15	0					
13.6	89						87	88	84	70	0	0	0			
11.5	89						86	88	85	69	8	0	0			
10.7	84						88	81	71	39	0	0	0			
9.9	87						84	86	81	72	57	0	0			
6.3	86							87	83	84	83	85	80	67	31	0
						16 WEEKS										
25.2	88	91	90	90	86	57	0	0								
23.4	86	89	88	81	80	72	13	0								
20.3			88	90	89	77	76	15	0							
17.6	87				91	85	87	77	71	0	0					
16.4					80	87	90	86	80	8	0					
13.6	84						90	87	88	72	0	0				
11.5	87						85	84	77	58	4	0	0			
10.7	87						88	83	74	53	0	0	0			
9.9	84						88	82	79	69	58	0	0			
6.3	87							81	83	84	80	76	77	69	26	0

24 WEEKS																
25.2	88	90	90	90	87	50	0	0								
23.4	89	91	88	87	80	74	11	0								
20.3			89	85	86	82	68	13	0							
17.6	86				90	90	86	83	73	0	0					
16.4					85	90	85	85	78	8	0					
13.6	88						90	86	85	65	0	0				
11.5	86						83	83	78	59	6	0				
10.7	87						82	82	69	39	0	0				
9.9	87						87	85	81	70	63	0	0			
6.3	85							85	86	84	83	85	80	65	27	0
32 WEEKS																
25.2	85	90	91	90	80	48	0	0								
23.4	87	90	86	85	85	67	11	0								
20.3			85	86	87	84	65	15	0							
17.6	89				87	89	86	83	69	0	0					
16.4					86	86	88	87	81	6	0					
13.6	86						90	89	88	64	0	0				
11.5	85						86	83	79	64	8	0				
10.7	86						85	79	73	48	0	0				
9.9	83						83	82	78	64	58	<1	0			
6.3	84							84	79	79	79	78	75	59	20	0

[1] Lot BB1.

Because more samples of rice of each moisture content were heat-treated in 1951 than in 1950 and at intervals of 3° instead of 5° C., germination data are available for 1 or 2 additional samples of rice of each moisture content, which have been heat-treated for 30 minutes within the damaging temperature range. The additional data permit closer approximations of the temperatures at which damage to viability just starts and at which it is just complete. They also present a clearer picture of the effect of heat within these temperature limitations.

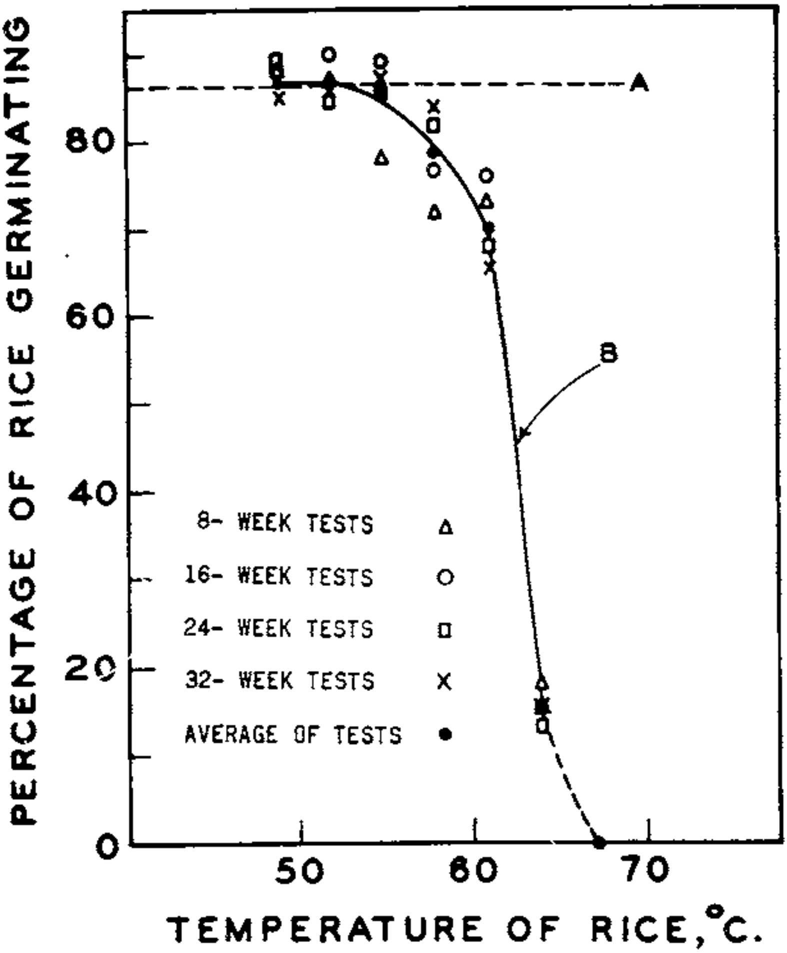

Figure 2.—Germination of Bluebonnet rice (lot BB1, table 6) after heat treatment at different temperatures for 30 minutes. A, Air-dried control, not heat-treated; B, rice containing 20.3 percent of moisture at the time of heat treatment. Values are averages of germination tests made after 8, 16, 24, and 32 weeks of storage at 24°–26° C.

These observations are illustrated in figure 2 for Bluebonnet rice of 20.3-percent moisture content. A sigmoid or S-type curve is obtained when the percentage of rice germinating is plotted against the temperature of treatment. The sharp drop in the slope of the curve for the higher temperatures of treatment within the damaging range proves their greater lethal action. Hutchinson (*33*) has published a similar type curve depicting the germination capacity of wheat of 14-percent moisture content after 36 minutes' heat treatment at 64°–73° C.

As in 1950 it was frequently observed that decreases in germination vigor could be detected at lower temperatures than could decreases in germination capacity. This finding is illustrated by the data in table 7. The heat treatment of samples of Bluebonnet of 25.2-percent moisture content for 30 minutes at temperatures of 49° and 52° C., respectively, did not cause a decrease in germination capacity. However, it did cause a decrease in germination vigor for the sample treated at the higher temperature. Also the greatest loss in germination vigor occurred in those samples having the highest moisture contents. Of course, the temperature had to be within the range damaging for the samples.

TABLE 7.—*Effects of temperature of heat treatment (30 minutes) and of moisture content on the germination of Bluebonnet* [1] *rough rice after 5, 7, 10, and 14 days, 1951. (32d-week germination data.)*

Variable	5 days	7 days	10 days	14 days	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Control [2]	84	2	1	0	87
Temperature (° C.): [3]					
46	85	4	1	0	90
49	89	2	0	0	91
52	65	21	2	2	90
55	46	24	6	4	80
58	1	15	12	20	48
61	0	0	0	0	0
Moisture (percent): [4]					
25.2	1	15	12	20	48
23.4	22	21	18	6	67
20.3	68	11	4	1	84
17.6	87	2	0	0	89

[1] Lot BB1.
[2] Average of 8 germination tests.
[3] Moisture content 25.2 percent.
[4] Heat-treated at 58° C.

Data similar to those for Bluebonnet in table 6 are presented for Sel. 61-25-12 in table 8.

TABLE 8.—*Germination of Sel. 61–25–12 rough rice 8, 16, 24, and 32 weeks after heat treatment for 30 minutes at different temperatures, 1951*

8 WEEKS

Moisture content (percent)	Control	49° C.	52° C.	55° C.	58° C.	61° C.	64° C.	67° C.	70° C.	73° C.	76° C.	79° C.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
19.8	78	84	80	72	70	64	56	5	0	0	--------	--------
18.2	81	--------	81	77	80	75	71	19	0	0	--------	--------
15.6	85	--------	--------	87	80	81	76	70	1	0	0	--------
14.0	80	--------	--------	--------	78	78	75	73	52	0	0	--------
12.4	81	--------	--------	--------	80	78	76	64	36	<1	0	0
10.1	81	--------	--------	--------	--------	78	75	71	39	<1	0	0
7.7	85	--------	--------	--------	--------	--------	77	80	75	52	<1	0

16 WEEKS

Moisture content (percent)	Control	49° C.	52° C.	55° C.	58° C.	61° C.	64° C.	67° C.	70° C.	73° C.	76° C.	79° C.
19.8	80	84	85	70	72	64	60	5	0	0	--------	--------
18.2	81	--------	79	79	79	73	65	19	0	0	--------	--------
15.6	79	--------	--------	82	82	79	78	60	1	0	0	--------
14.0	77	--------	--------	--------	80	81	78	73	56	0	0	--------
12.4	83	--------	--------	--------	80	85	73	69	38	0	0	--------
10.1	--------	--------	--------	--------	--------	82	82	74	42	0	0	--------
7.7	82	--------	--------	--------	--------	--------	83	82	77	55	<1	0

24 WEEKS

19.8	80	81	83	80	74	64	54	5	<1	----	----	----
18.2	73	----	83	80	81	77	71	22	0	----	----	----
15.6	83	----	----	87	85	82	83	67	<1	0	0	----
14.0	84	----	----	----	82	80	78	72	45	0	0	----
12.4	80	----	----	----	84	83	76	65	28	0	0	----
10.1	80	----	----	----	----	80	70	69	28	0	0	----
7.7	82	----	----	----	----	----	83	77	72	50	<1	0

32 WEEKS

19.8	77	78	82	78	71	65	56	7	0	0	----	----
18.2	77	----	83	81	79	70	73	22	0	0	----	----
15.6	83	----	----	82	83	81	82	68	1	0	0	----
14.0	80	----	----	----	81	81	81	72	52	0	0	----
12.4	81	----	----	----	78	74	78	63	28	0	0	----
10.1	81	----	----	----	----	80	72	71	29	<1	0	0
7.7	78	----	----	----	----	----	76	76	74	54	0	0

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TEMPERATURE AND TIME VARIABLES

In contrast to the 1950 experiments more extensive experimental evidence was obtained to show that the destruction of the germination capacity of rice with a given moisture content increases as the treatment time increases. Again this relationship was more evident when the temperature of treatment was within the range damaging to rice of a particular moisture content.

The percentages of Bluebonnet rough rice of 17.9-percent moisture content germinating 8, 16, 24, and 32 weeks after being heat-treated for periods of 10 to 120 minutes are given in table 9. The data, like those in tables 6 and 8, show that the differences in the germination percentages for the four periods are slight. They are also sufficiently inconsistent to suggest sampling errors and general experimental limitations.

TABLE 9.—*Germination of Bluebonnet*[1] *rough rice 8, 16, 24, and 32 weeks after heat treatment for different periods of time, 1951*

Temperature of treatment (° C.)	Control	10 min.	20 min.	30 min.	40 min.	50 min.	60 min.	90 min.	120 min.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
8 WEEKS									
55	95	92	95	94	90	92	90	93	92
60	94	93	91	83	78	88	91	93	92
65	94	78	73	80	79	81	79	65	53
70	92	15	0	0	0	0	0	0	0
16 WEEKS									
55	88	91	90	92	93	90	88	88	89
60	92	92	90	94	88	84	84	83	83
65	92	93	88	87	86	83	77	51	33
70	90	22	0	0	0	0	0	0	0
24 WEEKS									
55	91	89	88	89	89	89	89	87	87
60	94	88	90	89	88	85	85	84	89
65	94	88	88	90	83	81	77	60	52
70	91	14	0	0	0	0	0	0	0
32 WEEKS									
55	91	91	94	91	93	88	91	90	90
60	91	93	94	92	91	91	90	90	89
65	91	88	85	88	90	82	78	52	42
70	91	13	0	0	0	0	0	0	0

[1] Lot BB5.

Temperatures of 55° and 60° C. applied for as long as 120 minutes did not affect the germination capacity. In contrast, a temperature of

65° reduced the percentage of germinable seeds about one-half in 120 minutes. The evidence is not conclusive for the 65° heat treatments, but it indicates a gradual reduction in the percentage of germinable seeds starting with the 10-minute period. When the temperature of treatment was raised to 70°, the percentages of germinable seeds were reduced to 13–22 in 10 minutes and to 0 in 20 minutes.

A temperature of 55° C. applied for as long as 120 minutes did not have any effect on the germination vigor of Bluebonnet with 17.9-percent moisture content. At 60°, however, heat treatments for 50 minutes and longer did bring about a slight decrease in germination vigor, as indicated in table 10. Only the 32-week data are included because those for the other storage periods differed only in minor respects. All samples heat-treated at 65°, except possibly the one exposed for only 10 minutes, exhibited a loss in germination vigor. The loss was greater at this temperature the longer the period of treatment. Also the progressive loss of germination vigor was more apparent than that of germination capacity. At 70° the viability of most of the seeds was destroyed in 10 minutes and completely destroyed in 20.

TABLE 10.—*Effect of time (duration) of heat treatment at different temperatures on the germination of Bluebonnet*[1] *rough rice after 5, 7, 10, and 14 days, 1951. (32d-week germination data.)*

Duration of heat treatment (minutes)	5 days	7 days	10 days	14 days	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Control	88	2	1	0	91
AT 60° C.					
10	92	1	1	0	94
20	91	1	1	0	93
30	89	1	1	0	91
40	89	1	0	0	90
50	87	3	1	1	92
60	86	4	0	0	90
90	87	3	0	1	91
120	84	4	1	1	90
AT 65° C.					
10	83	3	2	0	88
20	74	9	2	0	85
30	67	16	4	1	88
40	60	20	8	2	90
50	57	15	8	2	82
60	48	19	8	3	78
90	14	18	13	7	52
120	6	15	13	8	42
AT 70° C.					
10	0	2	5	6	13
20	0	0	0	0	0

[1] Lot BB5.

TEMPERATURE, MOISTURE-CONTENT, AND MATURITY VARIABLES

Germination test data are given in table 11 for lots of rice hand-harvested and heat-treated from 2 to 20 days before the field was ready for combining.

Eleven lots with moisture contents from 31.3 to 32.4 percent were harvested on September 18–28. Samples of each were heat-treated for 30 minutes at 40°–64° C. in 3° intervals. The earlier samples with high moisture contents showed greater losses in germination capacity at the higher temperatures than the later samples. The control and the heat-treated samples with 32 percent of moisture of September 18 were slower to germinate, i. e., they exhibited a lower germination vigor, than the more mature samples with lower moisture contents from the lot combine-harvested on October 8. The air-dried control had slightly less germination vigor than the samples exposed to 40°, 43°, and 46° but more than those exposed to higher temperatures. The samples of September 19 also exhibited a lag in germinating but to a less degree in the control and also in the samples exposed to 40°, 43°, and 46°.

Samples of the remaining nine lots, September 20–28, did not exhibit any marked decrease in germination vigor over that of their respective controls except at 52° C. and higher. The air-dried controls for all lots including the one of October 8 exhibited some germination lag—more than was encountered in the same variety of rice in 1950 and in Bluebonnet in 1951. The effects of heat on the viability of rice samples from lots harvested from September 29 through October 8 were similar to those described for other experiments (tables 2, 6, and 8), in which moisture content of the rice and temperature of treatment have been the major variables.

When the maturity study was initiated on September 18, most of the kernels of Sel. 61-25-12 were firm, but green pigment predominated in most of the hulls. By September 28 the kernels were firmer and the hulls predominantly yellow. No objective evaluation of the changes in maturity from day to day was attempted. Weather conditions were cloudy, rainy, and generally unfavorable for loss of moisture from the grain. Notwithstanding the failure to explore the maturity factors, the experiment demonstrates that in a study of the effect of heat on rice viability, moisture content is of more practical significance than maturity.

Table 11.—*Germination of Sel. 61-25-12 rough rice of different maturities 32 weeks after heat treatment for 30 minutes at different temperatures, 1951*

Date of heat treatment	Time before harvest	Moisture content	Control	40° C.	43° C.	46° C.	49° C.	52° C.	55° C.	58° C.	61° C.	64° C.	67° C.
	Days	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Sept. 18	20	32.0	69	72	68	69	55	18	1	0	------	------	------
19	19	32.2	65	63	69	72	70	30	2	0	------	------	------
20	18	32.2	72	77	75	80	77	75	7	0	------	------	------
21	17	32.4	71	74	72	78	74	67	10	0	------	------	------
22	16	31.8	70	74	78	74	78	74	20	0	------	------	------
23	15	31.8	76	80	79	80	81	72	29	0	------	------	------
24	14	31.6	72	76	75	75	81	76	46	0	------	------	------
25	13	31.9	73	73	80	81	77	77	47	0	------	------	------
26	12	31.3	70	78	82	82	78	75	43	0	------	------	------
27	11	31.4	81	79	77	81	78	76	44	0	------	------	------
28	10	31.6	69	74	77	78	77	72	41	0	------	------	------
29	9	22.4	86	------	------	------	85	76	73	56	48	8	0
30	8	21.7	76	------	------	------	71	73	76	71	46	13	0
Oct. 1	7	23.0	74	------	------	------	81	81	73	59	25	0	0
2	6	28.2	77	------	85	83	83	86	73	35	<1	0	0
4	4	26.2	83	------	------	86	85	84	75	43	0	0	0
5	3	23.7	79	------	------	77	81	80	75	63	5	0	0
6	2	20.9	84	------	------	------	83	84	80	73	62	8	0
8	0	19.8	77	------	------	------	78	82	78	71	65	56	[1] 7

[1] At 70° C. showed 0-percent germination.

HEAT-TREATMENT EXPERIMENTS IN 1952

Although more detailed and confirmatory information concerning the effects of heat on the germination capacity and germination vigor of rough rice of different moisture contents was obtained in 1951 than in 1950, still much was left to be desired. Therefore, additional experiments having the same major objectives were planned.

A few minor modifications were made in the procedures. The "sliding temperature scale" was again employed, but the intervals between temperatures of treatment for rice of each moisture content were 3° C. in the lower portion of each range and 2° in the upper. For example, the temperatures of treatment selected for samples of rice of 21.6-percent moisture content were 45°, 48°, 51°, 54°, 57°, 59°, 61°, 63°, 65°, and 67°, and covered a range of 23°. Depending upon the moisture content, 10 to 17 samples were heat-treated over ranges of 21° to 40°. Data are not recorded (table 12), however, for all the samples treated at the higher temperatures that showed zero germination. Manometric measurements of the total pressures developed in the rice-packed test tubes, 16 by 150 mm., during heat treatment were made by the method described in Experimental Materials and Procedures (pp. 11–12).

In the experiment on the effect of temperature and time (duration) of heating on viability (table 15), samples were heat-treated from 10 to 120 minutes in 3° intervals from 52° to 70° C.

Germination tests were made only at the 8-week period, because in 1950 and 1951 neither the air-dried controls nor the heat-treated samples showed marked or consistently progressive differences in viability between the 16-, 24-, or 32-week period and the 8-week period.

Bluebonnet and Century 52 rice were used in the 1952 experiments (table 1). The Bluebonnet was of the same "release" used in 1951. The Century 52 was a variety developed by the Rice Experiment Station, Crowley, La. Bluebonnet was obtained in sufficient quantity to permit mechanical cleaning. A commercial-type cleaner utilizing both air blast and shaker removed the straw and other light debris.

TEMPERATURE AND MOISTURE-CONTENT VARIABLES

The effects of different temperatures of treatment on the germination capacities of samples of rice of different moisture contents (table 12) followed the same trends as in 1950 and 1951 (tables 2, 6, and 8). Also, the temperature at which rice of a given moisture content was just damaged could not be approximated with any greater degree of accuracy in 1952. Presumably the lot of Bluebonnet rice used either was not of the best quality or else had not been thoroughly cleaned of immature and damaged seed. Possibly it was damaged slightly in mechanical cleaning. Its germination capacity, based on 18 tests, ranged from 87 to 95 percent, with an average of 91 percent. The percentages of seed germinated after 5, 7, 10, and 14 days, calculated for the 18 tests, were 87, 3, 1, and 0 percent, respectively. Complete kills were not obtained at the higher temperatures, at which samples with moisture contents of 4.7, 5. and 5.8 percent were treated (table 12). At the time of heat treatment the moisture contents of

TABLE 12.—*Germination of Bluebonnet rough rice after heat treatm ent for 30 minutes at different temperatures, 1952*

Moisture content (percent)	Control	45° C.	47° C.	48° C.	50° C.	51° C.	53° C.	54° C.	55° C.	56° C.	57° C.	58° C.	59° C.	60° C.	61° C.	63° C.	64° C.	65° C.	66° C.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
21.6	87	88		90		91		91			79		76		80	78		20	
19.3	92		89		93		90			93			86		80	82		76	
17.2	92					90		92			91			95		94		82	
15.0	95							89			93			91		93			95
13.9	90							93			91			91		95			93
11.4	91								91			88			85		90		
9.7	91								89			88			90		81		
8.1	93								90			91			91		91		
5.8	91								90			89			91		91		
5.0	90								90			91			87		91		
4.7	91								90			91			89		90		

Moisture content (percent)	67° C.	68° C.	69° C.	70° C.	71° C.	72° C.	73° C.	74° C.	76° C.	78° C.	80° C.	82° C.	84° C.	86° C.	88° C.	90° C.	92° C.	94° C.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
21.6	0																	
19.3	55		1															
17.2	88		57		3		1											
15.0		89		68		0												
13.9		89		82		3		1	0									
11.4	92			89		58		1	4	2	0							
9.7	77			55		24		1	0									
8.1	88			75		73		26	1	0								
5.8	88			91		92		87	94	91	94	89	79					
5.0	90			89			91		92	93	91	91	92	90	86	68		
4.7	88			87			90		89	89	89	89	90	90	88	85	68	25

these three batches of Bluebonnet were estimated to be 2.5 to 2.7 percent higher than they actually were. Hence the temperatures investigated were thought to be adequate, and the error was not discovered until more accurate moisture determinations were made in the Southern Regional Research Laboratory on sealed samples.

No particular significance is attached to the pressures developed in the test tubes of Bluebonnet during heat treatment insofar as effect on germination capacity or germination vigor is concerned. As one would expect in view of the laws governing gases and vapor pressures, the highest pressures were developed in those test tubes that contained the rice of highest moisture content or that were heated at the highest temperature (table 13). To this extent the deleterious effect of pressure, if any, coincides with that of temperature and moisture content. In several series of tests (tables 12 and 13) the rough rice in test tubes developing approximately the same pressures did not always show the same degree of heat damage to germination capacity. This fact indicates that of the 3 variables—pressure, temperature, and moisture content—the last 2 are more important in these heat-treatment experiments.

The lowest temperature that will just cause detectable heat damage in Bluebonnet rice of a given moisture content in 30 minutes is not evident from the data in table 12. This observation is likewise true for the samples of Bluebonnet and Sel. 6I-25-12 that were similarly heat-treated in closed test tubes for 30 minutes in 1951 (tables 6 and 8). In these three experiments the first noticeable response of rough rice to the effect of heat was more often a loss in germination vigor than a loss in germination capacity. Because of this finding all the germination test data were reexamined. Attention was given to the percentages of seed of each sample that had germinated after 5, 7, and 10 days, as well as after 14 days. By comparing the differences in germination vigor of samples of rice of the same moisture content that had been heat-treated at several temperatures, it was possible to approximate the lowest temperature that might be expected to cause heat damage.

TABLE 13.—*Total pressures developed in packed test tubes of Bluebonnet rough rice of different moisture contents when heat-treated for 30 minutes at different temperatures, 1952*

Moisture content (percent)	45° C.	47° C.	48° C.	50° C.	51° C.	53° C.	54° C.	55° C.	56° C.	57° C.	58° C.	59° C.	60° C.	61° C.	63° C.	64° C.	65° C.	66° C.
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
21.6	5. 0				7. 3		9. 2			11. 7		12. 8		15. 7	17. 9		20. 4	
19.3		6. 4		7. 8		9. 9			11. 8			13. 3		15. 2	16. 7		18. 9	
17.2					9. 3		11. 8			14. 7			18. 0		11. 0		21. 9	
15.0							7. 9			11. 5			11. 7		16. 1			19. 6
13.9							9. 9			11. 9			16. 0		18. 2			21. 7
11.4								10. 0			10. 7			10. 4		17. 0		
9.7								9. 8			11. 1			7. 6		16. 4		
8.1								9. 1			11. 6			12. 7		14. 3		
5.8								8. 9			9. 7			10. 7		12. 5		
5.0								8. 6			9. 6			9. 5		11. 1		
4.7								9. 3			8. 9			9. 5		11. 5		

Moisture content (percent)	67° C.	68° C.	69° C.	70° C.	71° C.	72° C.	73° C.	74° C.	76° C.	78° C.	80° C.	82° C.	84° C.	86° C.	88° C.	90° C.	92° C.	94° C.
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
21.6	26. 4																	
19.3	21. 9		19. 5															
17.2	23. 2		28. 0				30. 0											
15.0		22. 3		20. 7		27. 9		31. 8	30. 1	33. 7								
13.9		23. 5		24. 8		26. 1		30. 2	32. 2	34. 9								
11.4	19. 4			18. 1		23. 5		26. 7	26. 3	28. 2	36. 6							
9.7	18. 5			20. 3		22. 2		25. 6	27. 4	29. 9	33. 0	35. 6						
8.1	17. 5			20. 2		20. 7		23. 2	26. 2	27. 2	31. 0	32. 2						
5.8	14. 7			16. 2		16. 3		20. 2	20. 5	21. 0	22. 2	26. 9	26. 6					
5.0	14. 0			15. 3			16. 6		19. 0	20. 5	23. 1	23. 1	23. 7	25. 2	26. 4	28. 7		
4.7	13. 4			14. 4			15. 1		17. 1	19. 7	22. 3	21. 6	23. 4	25. 5	25. 6	28. 6	30. 0	29. 0

Approximated temperatures at which heat damage to viability just starts and is just complete are given in table 14 for Bluebonnet and

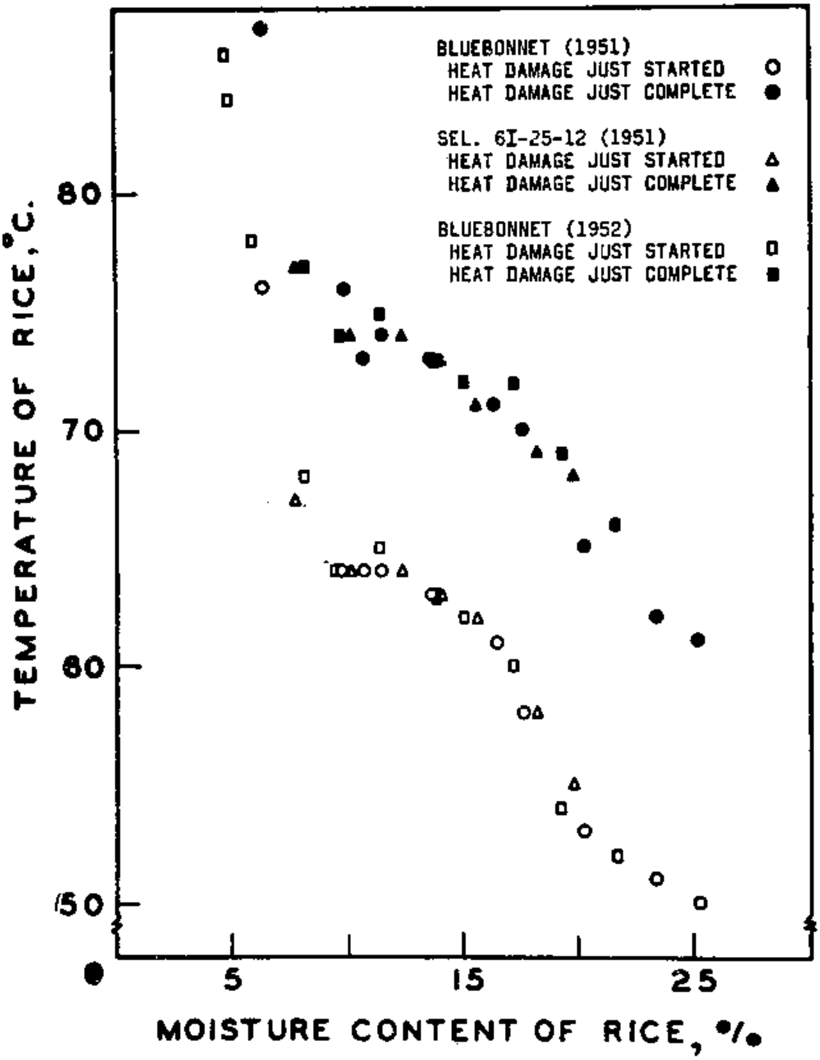

FIGURE 3.—Approximate limitations of the "zone of heat damage" for Bluebonnet and Sel. 6I-25-12 and the relationship of the moisture contents of the rice to the damaging temperatures. (Data from table 14.)

Sel. 6I-25-12 of several moisture contents. Table 14 and figure 3 show the relationship of the moisture contents of the rice to the damaging temperatures.

Figure 3 is a scatter-type diagram of the data presented in table 14. Each temperature is plotted against the moisture content of the rice. A "zone of heat damage" is clearly pictured, but its upper and lower boundaries are not so sharply and regularly defined as one might hope.

TABLE 14.—*Approximated temperatures at which heat damage just starts and is just complete for rough rice of different moisture contents, 1951–52*

Variety and percent moisture content	Heat damage starts	Heat damage complete
Bluebonnet (BB1) (1951):	° C.	° C.
25.2	50	61
23.4	51	62
20.3	53	65
17.6	58	70
16.4	61	71
13.6	63	73
11.5	64	74
10.7	64	73
9.9	64	76
6.3	76	87
Sel. 61–25–12 (3/4 BR23) (1951):		
19.8	55	68
18.2	58	69
15.6	62	71
14.0	63	73
12.4	64	74
10.1	64	74
7.7	67	77
Bluebonnet (BB10) (1952):		
21.6	52	66
19.3	54	69
17.2	60	72
15.0	62	72
13.9	63	73
11.4	65	75
9.7	64	74
8.1	68	77
5.8	78	----------
5.0	84	----------
4.7	86	----------

TEMPERATURE AND TIME VARIABLES

Percentages of rough rice in samples of Century 52 germinating 8 weeks after being heat-treated for periods of 10 to 120 minutes are given in table 15. Here the same time-temperature effects on germination capacity are demonstrated, but in greater detail than for Rexoro (table 4) or Bluebonnet (table 9).

The germination capacity of the Century 52 air-dried control, based on 7 tests, amounted to 94 percent. Its germination vigor is expressed by the percentages germinating after 5, 7, 10, and 14 days, which were 88, 5, 1, and 0, respectively.

The germination capacities of the heat-treated samples were but slightly affected by temperatures of treatment below 61° C. At 61° for 20 minutes or longer the counts dropped to 87–92 percent. On the other hand, all samples heat-treated at 64° for 10 to 120 minutes underwent an appreciably greater progressive loss in germination capacity with increased time of treatment, and the counts dropped to

TABLE 15.—*Germination of Century 52 rough rice after heat treatment for different periods of time, 1952*

Temperature of treatment (° C.)	Control	10 min.	20 min.	30 min.	40 min.	50 min.	60 min.	70 min.	80 min.	90 min.	100 min.	110 min.	120 min.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
52	95	93	..	95	..	..	93	..	..	94	95	95	95
55	95	95	94	96	95	92	94	94	92	92	95	95	93
58	94	93	97	97	94	94	93	89	92	91	94	91	90
61	95	95	92	90	87	90	92	89	87	90	88	88	89
64	94	91	89	89	88	85	82	84	69	68	67	62	47
67	93	87	76	55	37	12	7	2	1	0	0	0	0
70	95	52	10	0	0	0	0	..	..	..	..	..	..

47–91 percent. The destruction of germination capacity was correspondingly greater at the two highest temperatures. There were no viable seeds in samples treated for 90 minutes or longer at 67° or for 30 minutes or longer at 70°.

A loss in germination vigor occurred in samples of Century 52 heat-treated for 30 minutes or longer at 55° C. and in all those heat-treated at the higher temperatures. The extent of this loss is reflected in the germination data in table 16. The percentages of rice germinating after 5, 7, 10, and 14 days are given for all samples heat-treated at 61°, 64°, 67°, and 70°—the temperatures that definitely affected germination capacity. The percentages show that the longer the treatment or the higher the temperature of treatment for rice of a given moisture content, the longer it takes the remaining viable seeds in the sample to germinate. Again, this observation holds only if the temperature of treatment falls within the zone of heat damage for rice of the specified moisture content.

TABLE 16.—*Effect of time (duration) of heat treatment at different temperatures on the germination of Century 52 rough rice after 5, 7, 10, and 14 days, 1952*

Duration of heat treatment (minutes)	At 61° C.					At 64° C.				
	5 days	7 days	10 days	14 days	Total	5 days	7 days	10 days	14 days	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Control	92	2	1	0	95	88	4	2	0	94
10	83	8	3	1	95	59	23	8	1	91
20	76	11	4	1	92	11	33	14	1	89
30	72	11	6	1	90	31	39	14	2	89
40	58	22	5	2	87	22	54	10	2	88
50	55	25	6	4	90	17	56	11	1	85
60	64	19	7	2	92	15	52	13	2	82
70	58	23	6	2	89	11	56	11	3	84
80	41	33	10	3	87	0	45	19	5	69
90	46	33	9	2	90	0	38	22	8	68
100	46	31	8	3	88	0	39	23	5	67
110	48	35	3	2	88	0	32	23	7	62
120	49	33	6	1	80	0	22	17	8	47
	At 67° C.					At 70° C.				
Control	85	7	1	0	93	88	6	1	0	95
10	8	63	15	1	87	1	27	18	6	52
20	2	59	13	2	76	0	0	6	4	10
30	0	36	15	1	55	0	0	0	0	0
40	0	15	18	4	37					
50	0	2	7	3	12					
60	0	1	3	3	7					
70	0	0	0	2	2					
80	0	0	0	1	1					
90	0	0	0	0	0					

THE GERMINATION TESTS

SEEDLING ABNORMALITIES

Although several hundred germination tests were made during the 3-year investigations, no distinctive abnormalities in the sturcture of the seedlings were observed that could be definitely attributed to heat injury. The same kinds of abnormal seedlings were observed when heat-treated samples of rice and unheated air-dried controls were germinated. Abnormal types were most often found among seedlings counted at 7, 10, and 14 days. The most common type had a spindly primary root and secondary roots. There were also other kinds similar in appearance to those illustrated in Agricultural Handbook No. 30 (*84*).

That high-temperature injury may be reflected in seedling development is well known. Haberlandt (*31*) heated different kinds of seeds for 48 hours at 100° C. When they were germinated, he found that the plumule developed before the rootlet and even that the stem might start to develop, though the root remained entirely undeveloped. Sachs' (*68*) tabulations record a higher ratio of stunted to normal embyros the higher the temperature of treatment. Dixon (*26*) observed in the germination of heat-treated seeds that "The most frequent abnormality is the protrusion of the cotyledons instead of the radicle from the seed. . . . Even if the radicle does emerge normally, it is often abnormal in its subsequent behavior." Hutchinson (*33*) reported that his heat-treated wheat seeds ". . . germinating after slight delay were all normal as regards roots and shoots, but a few of those showing severe delay were stunted."

Hutchinson *et al.* (*34*) have stated that "As with other forms of biological damage, mild heat damage in oats, barley and wheat is reversible, but severe damage causes death of the cells." In addition, their evidence ". . . indicated that heated grain needed optimum conditions of water and aeration in the primary stages, but that after growth had commenced it behaved in a normal manner." They felt that the heat-damaged cell had lost some of its power of selective permeability, and that ". . . vitality as judged by ability to withstand excess water and other sub-optimal germination conditions is probably adversely affected." They noted cytological differences in normal and heat-damaged grain.

DRY SEED

In the 1950 experiments the rough rice with moisture contents of 3.5–3.8 percent had shorter roots and shoots than control seed of higher moisture contents even when the temperature of treatment of the low moisture-content samples was considered below the critical range. On the other hand, no differences in germination capacity are reflected in the data in table 2. The reason is that samples of air-dried controls with both the low and the higher moisture content yielded essentially the same number of countable seedlings after 5, 7, 10, and 14 days in the germinator. Many more of the seedlings, however, from the drier samples barely met the arbitrarily selected minimum requirements to be counted, i. e., possessed both root and shoot with one structure at least one-fourth inch long.

Haberlandt (*31*) believed that a hardening of the seeds and seed coats as a result of extensive drying at a high temperature might be the partial explanation for retardation in growth. This condition would permit only the very gradual entrance of moisture into the inner seed. Just (*43*) and Dixon (*26*) expressed similar thoughts.

EXCESSIVELY WET SEEDBED

Sometimes in the germination tests the beds of paper toweling became extremely wet. Seeds in the excessively wet beds germinated more slowly. Root (radicle) formation was retarded, and when the root did form it was usually free of root hairs. This kind of development is attributed to reduced oxygen tension.

The phenomenon has been extensively reported in the literature, and has been observed to occur in air with reduced oxygen, in nitrogen, and in water, and to be affected by different depths of water, sand, and soil. Klebs (*45*) in 1885, Yokoi (*91*) in 1898, and Takahashi (*80*) in 1905 were among the first to record observations similar to the above. Since then the phenomenon has been reported by others, including Atemine (*7*), Nagai (*65*), Morinaga (*62*), Sasaki (*69*), Jones (*40*), Dastur and Desai (*22*), Alam (*2*), Taylor (*81*), and Vlamis and Davis (*86*). In the germination of rice seed the shoot appears first and, according to Atemine, if the apical root emerges first, it is probably because of deficient moisture. Alam attributed the failure of secondary and adventitious roots to develop in seedlings planted at greater depths in soil to the greater restriction of the oxygen supply. Erygin (*30*) found the enzyme activity to be less in seed germinated under water. Morinaga (*62*) demonstrated that the catalase activity of seedlings grown under water is reduced the greater the depth of the water. A common practice in the Southern rice-growing States is to plant at a depth of 1 to 2 inches with a drill and to flood the field after the rice is 4 to 6 inches high (Jones *et al.* *41*).

RESISTANCE TO FUNGI

Rough rice seeds whose ability to germinate had been completely destroyed were more readily attacked by fungi than viable seeds. Haberlandt (*31*) found that if the germinating power is destroyed, the moist seeds become sticky and ill-smelling within a few days, whereas with live seeds the seed coats may remain unaltered for several weeks. Just's (*43*) tabulated data showed early putrefaction of his nonviable heat-treated seed samples. Dixon (*26*) sterilized the sand, saucers, and water used for the germination test. He wrote, "This precaution appears necessary, as the diminished vitality of seeds when exposed to temperatures near their maximum renders them very susceptible to the attacks of micro-organisms."

IMPROVED GERMINATION

Except for the most immature rice samples heat-treated during the 1951 experiments (table 11), no evidence was obtained that heat treatments as such improved viability. More evidence might have been obtained had the average lengths of roots and shoots been determined in all heat-treated samples and controls.

No experimental evidence was obtained to indicate whether the heat treatments had any effect in overcoming dormancy of the different varieties of rice. Germination tests were not made until 8 weeks after heat treatment. Any dormancy existing at the time of harvest might have disappeared during this interval.

According to Wiesner's (*90*) work with conifer seeds, the effects of heat treatment may be beneficial to germination. Just (*43*) reported one experiment in which the germination capacity and vigor of barley were improved by heat treatment. The barley seed was held 2 days over sulfuric acid, then put in a test tube with calcium chloride and left for 2 more days, then held 1 day at 30° and 3 days at 60° C. Kiessling (*44*) in studying the effects of heat treatments on dormancy found that heat treatments improved the germinating quality of "nongerm-ripe" barley, but they did not fully compensate for complete storage ripeness. Another important observation was that the improvement in germinating quality was independent of the alteration of the moisture content. He was referring to those losses that occur when seeds are dried at the same time they are being heat-treated. Da Fano's data (*27*) show improved germination of rice after heating at 30°–70°, and of corn after heating at 30°–60°.

GENERAL DISCUSSION

Weather conditions together with other circumstances in 1950, 1951, and 1952 prevented the authors from obtaining lots of freshly combined rough rice of higher than 25.2-percent moisture content. It would have been desirable to have included experiments on the effects of temperature of treatment on lots of rice of 26- to 30-percent moisture contents. These moisture contents, although uncommon, are possible. Furthermore, it would have been desirable, from the standpoint of commercial harvesting conditions, to have used lots of rice freshly combined at each 2-percent difference in moisture level, at least within the range of 16 to 26 percent. Because it was not practical to attempt to combine rice at specified moisture-content levels, advantage was taken of an alternative procedure, in which a barrel or more of rice was taken from a freshly combined lot of high moisture content and portions were air-dried to different moisture levels.

It was anticipated that heat treatments at increasingly higher temperatures would bring about increasingly greater reduction in the ability of rice to germinate. The earlier investigators recognized the significance of the temperature variable. Their numerous experiments demonstrated the greater destructiveness of the higher temperatures to germinability. Nevertheless, several reasons exist for not accepting their data and conclusions as final and directly applicable to the heat treatment of rice. For example, specific details regarding the moisture contents of the seeds, the methods of heat treatment, and the age of the seeds were frequently omitted. Seeds were sometimes exposed to very high temperatures and for unusually long periods of time. They were artificially moistened when it was desired to determine the effects of heat on seeds of high moisture content. Germination tests were generally made immediately or shortly after heat treatment. Many of the seeds studied differed structurally from rice. Moreover, most of the investigators had different objectives in planning their experiments.

The experiments reported in this bulletin differed in the following ways from those of earlier workers:

1. Heat treatments were conducted only with freshly and/or recently combined rough rice.

2. Naturally moist rough rice was used in experiments requiring rough rice of high moisture content.

3. Times and temperatures of treatment included those within ranges covered in present-day practices of commercial rice drying.

4. Containers in which the rough rice was to be heat-treated were packed full and tightly stoppered so that there would be little moisture loss from the seed mass during the application of heat.

5. Samples of heat-treated rough rice were tested for their contents of germinable seeds after different periods of storage.

Although there are numerous reasons for not accepting in toto all the earlier observations concerning the effects of heat on the ability of seed to germinate, many of the earlier more general observations do apply to rice. Their chronology is briefly reviewed here. This is done to give prior research credit, to approximate the order of development of the pertinent observations, to indicate similarities in the responses of different kinds of seeds, and to facilitate the reader's evaluation of the data presented in this bulletin.

Workers who have demonstrated that heat treatment at a high temperature reduced or entirely destroyed the ability of seeds to germinate include Edwards and Colin (*28*) in 1834, Haberlandt (*31*) in 1863, Sachs (*68*) in 1865, Wiesner (*90*) in 1871, Just (*42*, *43*) in 1877, Von Höhnel (*32*) in 1877, Dixon (*25*, *26*, *27*) in 1901–3, White (*89*) in 1909, and Burgess (*15*) in 1919. This finding has since been confirmed by Da Fano (*21*) in 1916 and Jones (*39*) in 1926 for rice. It may be assumed that all these investigators fully recognized that dry seeds have greater resistance to high temperatures than seeds with high moisture content.

Haberlandt (*31*) exposed 88 kinds of seeds for 48 hours in a drying apparatus at 37.5°, 56.3°, 75°, 87.5°, and 100° C. He reported his data in terms of the number of days it took seeds exposed at each temperature to germinate. Two kinds lost their ability to germinate when treated at 87.5° and 10 more at 100°. Although losses in germination capacity under 100 percent are not evident from the tabulated data, they as well as losses in germination vigor are discussed. Haberlandt wrote that the seeds of most cultivated plants, with few exceptions, are able to endure a temperature of 100° without losing their ability to germinate.

Sachs (*68*) recorded his data in terms of the number of seeds that germinated out of the 100 planted. Normal and stunted embryos are separately itemized. Data are given for dry pea, rye, barley, wheat, and corn seed heat-treated in test tubes for 1 hour in a water bath at temperatures ranging from 57° or 58° to 74° C. Data are also given for the same kinds of seed, wet and similarly heat-treated at temperatures ranging from 49° or 50° to 54° or 55°. Sachs found that the loss in viability was greater the higher the temperature of treatment and that it was much greater in wet than in dry seed.

Just's (*43*) comprehensive study is probably the first to show several interrelationships between the temperature of treatment, the duration of treatment, and the moisture content of the seed. He heat-treated oats and barley of different moisture contents in a constant-temperature oven at different temperatures and for different periods of time. He tabulated germination data for each day of the test period. Consequently, his data show the effects of heat on the germination capacity and the germination vigor and the day of maximum germination. Moreover, they show that the greater the injury the longer is the interval preceding the day of maximum germination and that in severe injury a day of maximum germination is not evident. Just verified the findings of his predecessors in that he clearly demonstrated greater destruction of viability the higher the temperature, the longer the treatment, and the higher the moisture content of the seed.

Just (*43*) and Von Höhnel (*32*), who also published in 1877, summed up the effects of heat on the viability of seed much as we understand it today. Both investigators realized that one could not give a definite maximum temperature at which seeds could be heat-treated without injury. Von Höhnel has pointed out, more clearly perhaps than Just, that the first symptom of injury through heating consists of a loss in germination vigor and that it may occur even though no loss in germination capacity is noticeable.

Twenty-five years after the publications of Just and Von Höhnel, Dixon (*26*) made a significant generalization in analyzing his seed heat-treatment data. He wrote ". . . it appears that for each seed there is a temperature up to which it may be raised without suffering appreciable alteration in the period of time needed for germination. Once this point is passed the germination period is increased, the increase per degree being greater, the nearer the maximum is approached." This generalization had apparently been assumed or else overlooked by earlier investigators because their interest was primarily in determining the maximum temperatures seeds could endure without injury. It is the range of temperatures over which a given lot of seed may be heat-treated without injury that is recognized today as being highly important for the development of commercial drying and storage methods. The lower the moisture content of the seed, the greater the temperature range over which it may be safely heat-treated.

In 1911 Kiessling (*44*) concluded that the effect of heat in overcoming the dormancy of barley that was not "storage ripe" was independent of the loss of moisture. From this finding we may assume that the more accurate data in the literature on the effects of heat per se were probably obtained by those investigators who exposed their seeds in closed containers or under conditions in which the moisture loss was negligible. In 1917 Waggoner (*87*) emphasized that the difficulty in interpreting data in the older literature with respect to the lethal temperatures of seeds ". . . was to be sought in the initial water content of the seeds or in the method employed that would allow an increase or decrease of this water content during the heating process."

Waggoner's experiments with radish seed and Hutchinson's (*33*) with wheat confirm previous observations of the effect of heat on the viability of seed.

The general observations made by the authors of this bulletin on their rough rice investigations are largely a recapitulation of those that have just been reviewed. The viability of rough rice has been shown to be affected by heat in the same manner as the viabilities of radish, wheat, and other seeds similarly treated. Differences in resistance between the different kinds of seeds as judged from the present rice study and the literature are more of degree than of kind.

On the other hand, some observations were made during these investigations that have not previously been emphasized. Rough rice was heated in closed containers and apparently without the development of injurious pressure effects. In heat-treating immature rice moisture content rather than stage of maturity was the major factor determining the degree of heat injury. Heat-treated rice, even heat-damaged samples, did not show any appreciable change in viability, i. e., in the percentages of seed germinating, between the 8- and 32-week periods of storage.

Rough rice that was naturally moist and freshly combined was used in the experiments because it was thought that the data would be more represenative of data obtained under large-scale commercial operations. Whether this reasoning was correct was not determined.

Certain disadvantages in using freshly combined rice soon became apparent. The lots not only lacked uniformity but sometimes contained large percentages of nonviable seed. As a result the temperatures at which heat damage to viability just started and at which it was just complete for rice of a given moisture content could be only roughly approximated. This fact discouraged any endeavor to derive mathematical equations, such as those of Hutchinson (*33*) for wheat, which might have practical value in determining safe commercial operating conditions for heat-treating rough rice. It is evident (figure 3) that the approximations defining the critical temperature range for rice of each moisture content investigated do outline a zone of heat damage. It is also evident that their pattern is too irregular to define the lower and upper limits of the zone of heat damage.

Under different experimental conditions it might have been possible to obtain data that would more accurately illustrate the limits of the zone of heat damage for rough rice of different moisture contents. Von Höhnel (*32*) found that a definite maximum temperature at which a given sample of seeds may be safely heated may not be obtained because of the differences in the resistances of individual seeds. Hutchinson (*33*), on the other hand, was able to establish rather definite and practical temperature end points defining the critical ranges for each of his samples of wheat of different moisture contents. From his publication it would appear that the selection of uniform seed samples and the choice of ones containing as near 100 percent of viable seed as possible were important factors.

Although there may be an error of ±3° C. or more in the approximated temperatures plotted in figure 3, the scatter-type diagram has practical value. It enables one to approximate the maximum temperatures at which batches of rough rice of different moisture contents may be heat-treated under conditions like those described in Experimental Materials and Procedures (pp. 8–12). To this extent it may serve as a heat-damage prediction or safety chart. No claims may be made that it would serve reliably for predetermining the temperature at which a freshly combined lot of rice might be safely dried in a commercial drier. The reason is that the variable introduced by the loss of moisture during the heating process was not evaluated in the investigations.

However, it appears possible that diagrams similar to figure 3 could be developed for use as heat-damage prediction charts for guiding experimental and commercial drying operations for both seed and milling purposes. Charts for the latter would need to be based upon milling instead of germination test data.

SEED HEAT-TREATMENT METHODS AND THEIR APPLICATIONS

Plant physiologists, plant pathologists, entomologists, and agricultural engineers have made the major contributions to our knowledge of the effects of heat on seeds.

Atanasoff and Johnson (*6*) pointed out that the first workers to investigate the effects of different temperatures of treatment on seeds were principally plant physiologists and then plant pathologists. The plant physiologists were interested in establishing the effects of heat on germination capacity and germination vigor and in overcoming dormancy. Often they employed very high temperatures and long exposure periods, which we consider today to be extreme and impractical for commercial application.

The plant pathologists perceived that heat might be useful for destroying seed-contaminating fungi, which might later become actively pathogenic to the seed or to the developing embryo and plant. These workers had to devise experiments that would demonstrate whether a certain time-temperature combination might be employed in treating a given kind of seed that would destroy the contaminating pathogenic fungi but that would not affect the viability of the seed. Shortly the entomologists became interested. They had essentially the same problems as the plant pathologists since they needed to preserve seed for extended periods for both planting and milling purposes. Most of the literature on the use of heat to destroy fungi and insects in seeds has appeared within the past 50 years. This is not because the concepts for these two practical applications of heat are by any means new. Haberlandt (*31*) discussed them in 1863 and no doubt others before him.

Within the past 25 years agricultural engineers and associated workers have made numerous worthy contributions to the literature on the heat treatment of seed. Their dual objectives have been, by means of drying and controlled temperatures and humidities, to prevent the development and activity of fungi and insects in stored seed and either to improve or to assure the retention of high milling quality in grains.

Several methods for heat-treating seeds have been devised by the various workers. The kind of method is not necessarily correlatable with the professional interest of the investigator and no such inference is intended. The methods may be grouped as follows:

1. Direct contact with hot water.
2. Direct contact with heated air.

Trays in a constant-temperature oven; air circulation principally convection.

Open test tubes or flasks partially submerged in a bath; air circulation restricted, sometimes very much so by a capillary opening; insignificant total and vapor pressures.

Forced-draft experimental apparatus or equipment.
Heated dry air.
Heated moist air.
Vapor-heat machines.
Commercial driers and bins aerated with artificially heated air.
3. Closed containers. Submerged in a heated liquid bath: moisture loss from seed and available oxygen and air supply restricted.
4. Direct contact with liquids other than water.

In most of the investigations cited seeds have been exposed to a given temperature in direct contact with water or air or in a closed container.

DIRECT CONTACT WITH HOT WATER

Seeds in direct contact with hot water are said to be sensitive to heat. Possibly this condition is in part attributable to the more rapid and uniform penetration of the heat. The method, although fairly efficient in destroying fungi, has some objectionable features. A major one is that there is very little difference between the temperatures at which viability and contaminating fungi are destroyed. Tisdale (*82*), Adair and Cralley (*1*), and Cralley (*18*) have used hot water for the treatment of rice with fungi and nematodes. Additional information on the hot-water treatment is to be found in the publications of Edwards and Colin (*28*), Jensen (*36*), Kiessling (*44*), Waggoner (*87*), Lehman (*53*), and Watson *et al.* (*88*).

DIRECT CONTACT WITH HEATED AIR

Primary objections to the use of artificially heated dry air in treating seed is that it generally takes too long to obtain effective results and the seed may become too dry. Jensen (*36*) was unsuccessful in destroying smut in oat and barley seed in 7 hours at either 50° or 53.9° C. On the other hand, Atanasoff and Johnson (*6*) found that by exposing the well-dried seeds of barley, wheat, rye, and oats to dry heat for 30 hours, bacterial and fungal infections could be reduced or eliminated without materially injuring the germination of the seed. Lehman (*53*) recommended a dry-heat temperature of 95° for 12 hours for destroying the anthracnose fungus of cottonseed. To avoid serious loss of viability the seeds first had to be predried to a moisture-content value equivalent to 3.2 percent of their air-dry weight.

The use of dry heat for destroying weevils and other insects in grain, including rice, has been investigated by Popenoe (*66*), Dean (*23, 24*), and Cotton (*17*). Back and Cotton (*9*) were able to kill the rice weevil (*Sitophilus Oryza* (L.)) at 48.9° C. in 3 hours and at 54.4° within 30 minutes. Balzer and Cotton (*10*) found that exposure of 10 minutes to a temperature of 60° is fatal to all insects infesting stored rice. However, they were not successful in obtaining a satisfactory kill of insects in rice in a commercial drier operated at 60° for 30 minutes because the treatment did not raise the temperature of the rice above 50°. They stated that heating for insect control is not favored by the rice industry because the rice is apt to check and because too much moisture is removed.

Edwards and Colin (*28*) and Jodin (*37*) have shown that moist heat is only slightly less destructive to seed viability, and Jensen (*36*) observed it to be less effective than the hot-water treatment in the prevention of smut in oats and barley. On the other hand, Miller and McWhorter (*61*) have demonstrated the usefulness of vapor heat (steam-air mixture) as a practical means of disinfecting seed. These investigators found that certain kinds of seeds will apparently endure considerably higher vapor-heat temperatures than are required to kill all associated fungi. Thus, table beet seed balls will evidently tolerate a vapor-heat temperature of about 62.8° C. for as long as 30 minutes without significant reduction or retardation of germination. *Phoma betae*, an associated pathogen, is killed when exposed at 57.2° for 20 minutes, which is about 5.5° lower than the phytolethal temperature. Latta (*52*) used vapor heat in effectively controlling narcissus pests.

CLOSED CONTAINERS

The method of heating seed in closed containers is more nearly comparable with the moist- and vapor-heat methods than with either the hot-water or the artificially heated dry-air methods. The essential differences between the moist-heat and closed-container methods are that in the latter the atmospheric moisture present is largely derived from the seed and a pressure develops in the container, which is proportional to the available free moisture and time and temperature of treatment. Whether these differences offer advantages was not determined.

Jodin (*37*) and Waggoner (*87*) reported that seeds heated in a closed container could not stand so high a temperature as when heated in an open vessel or in an oven, which permitted the rapid elimination of water from the seed. Waggoner's data also showed clearly that radish seeds heated directly in water had less resistance than when they were heated in a closed container.

No studies comparing the relative efficiencies of the different methods of heat treatment have been made in which the same lot of rice was used. However, insofar as may be determined from the literature, the experimental data reported for rough rice in this bulletin indicate that rice can tolerate higher temperatures without loss of viability than are recommended for use in commercial drying operations. In commercial drying the moisture is continuously removed from the rice, and theoretically the kernels should become increasingly resistant. If it is true that the viability of rice may be destroyed at lower temperatures in a commercial drier than in a closed test tube, it would prove that factors other than heat are also in operation, which are destructive to viability.

DIRECT CONTACT WITH LIQUIDS OTHER THAN WATER

Watson *et al.* (*88*) selected several materials as possible treating agents for peas, beans, and lima beans. These materials were "carbon tetrachloride, mineral oil, Shell cleaner, Prestone (ethylene glycol), motor oil (S. A. E. 10), roccal, methyl alcohol, kerosene, xylol, lactic acid solutions, toluene, acetone, glycerine, cedar oil, aniline oil, olive oil, sodium chloride solutions, and cotton seed oil." Data were tabulated for seeds treated in carbon tetrachloride, motor oil, fuel oil, and water at temperatures ranging from 60° to 90° C. and for periods of 10 to 60 minutes. Beans, peas, and lima beans were able to survive extended exposures in hot carbon tetrachloride, but they were killed in a relatively short time when exposed in water of the same temperature. Carbon tetrachloride appeared to be the best medium tested, and the use of hot carbon tetrachloride for destroying seed-borne organisms in peas and beans is suggested. However, these authors have pointed out that "Further research will be necessary to evaluate the practical use of the materials and heat on the control of seed-borne pathogens."

Cruickshank (*19*) has recently carried out a series of preliminary experiments to determine the effect of a carbon tetrachloride steep on the germination and control of *Sphaerella linorum* Wollenw. in two varieties of linseed—Golden Viking and Koto. He obtained a significant depression of seed germination only at 70° and 75° C. for 30 minutes with Golden Viking and 20 minutes with Koto. Germination of the fungus spores was not observed to occur after treatment for 20 minutes at 65°, 70°, and 75° or for 30 minutes at 60°. He found that carbon tetrachloride has the following advantages over water for the heat treatment of linseed: It is safer with respect to germination and no artificial drying of the seed is necessary.

NEW METHODS AND MODIFICATIONS

It is evident from the information in this bulletin that man is a long way from having a comprehensive, scientifically derived knowledge of the effects of heat on rice. Rough rice has been demonstrated in the experiments in 1950, 1951, and 1952 to have a high resistance to heat. This characteristic suggests that heat might be used even more extensively than now for the improvement and stabilization of seed quality. Certainly the techniques for applying heat in the treatment of rice have by no means been fully explored. The practicability of using a very high temperature and "flash-heating," as well as the heat treatment of rice in media other than air and water, should be investigated. The possibility of simultaneously incorporating fungicidal substances and nutrients in the hulls should also be considered.

SUMMARY

Experiments were undertaken during the rice-harvesting seasons of 1950, 1951, and 1952 to demonstrate the effects of time and temperature of heating on the viability of rough, or paddy, rice (*Oryza sativa*) of different moisture contents. Both medium-grain (Sel. 61–25–12 and Zenith) and long-grain (Rexoro, Bluebonnet, and Century 52) varieties were used. Germination test data for rice and seed heat-treatment methods and their applications are discussed.

Heat treatments were made near sources of freshly combine-harvested rice—on the premises of the Rice Experiment Station at Crowley, La. Samples of naturally moist rough rice were packed in heat-resistant test tubes. The test tubes were tightly stoppered

and submerged in water baths maintained at different constant temperatures. In experiments to demonstrate the effect of temperature on viability, the usual period of exposure was 30 minutes after the rice reached the temperature of the bath. In experiments to demonstrate the effect of time (duration) of heating on viability, the periods of exposure ranged from 10 to 120 minutes. No moisture was lost from or gained access to the rice-filled test tubes during the periods of heat treatment. The rice in the test tubes was allowed up to 8 minutes to reach the temperature of the bath. On completion of the heat treatment the contents of the test tubes were composited and spread in a paper tray to air-dry. At the conclusion of each season's work all the air-dried heat-treated samples, together with appropriate air-dried controls (non-heat-treated), were packaged in paper bags, transferred to the Southern Regional Research Laboratory, New Orleans, La., and stored at 24°–26° C. Germination tests were made on each sample by the method prescribed by the Federal Seed Act, and were run 8, 16, 24, and 32 weeks after the date of heat treatment.

The germination test data confirm that high temperatures affected the viability of naturally moist rough rice in much the same manner as they affected the viabilities of other kinds of seeds similarly treated. The following general observations could be made:

For rough rice of each moisture content there is a temperature of heat treatment below which there is no decrease in viability.

For a given sample of rice the "zone of heat damage," i. e., the range between the temperature at which heat damage to viability just starts and the temperature at which it is just complete, is a narrow one. The extent of this range for a heat-treatment period of 30 minutes was not definitely established for the naturally moist combine-harvested rough rice used, but based on approximations of the limiting temperatures it appears to be between 8° and 12° C. This range is about the same for rice of different moisture contents, but it is higher on the temperature scale the lower the moisture content of the rice.

Within the zone of heat damage for rice of a given moisture content the degree of destruction increases as the temperature increases; also the longer the rice is heat-treated, the greater are its losses in germination capacity and germination vigor.

The resistance of rough rice to the impairment of its viability by heat varies inversely as its moisture content.

When the viability of rice is damaged by heat, loss in germination vigor is apparent before loss in germination capacity. Whether there is evidence of the latter depends upon the severity of the treatment.

Germination tests made 8, 16, 24, and 32 weeks after heat treatment on rice from the same heat-treated sample stored at 24°–26° C. did not reveal appreciable changes in the germination vigor and germination capacity of the sample.

In experiments with immature rice, the moisture-content variable exercised greater influence than the maturity variable in determining the resistance of the immature seed to heat damage.

Because of limited data it could not be determined whether the varieties of rice used differed significantly in their resistance to heat. Observed differences were minor and believed within experimental limitations. For the same reason it could not be determined whether the total pressures developed in the test tubes of packed rice during heat treatment had any significant effect on the viability of the heat-treated seed.

When the approximated temperatures defining the range of heat damage to viability were plotted for several samples of rice of different moisture contents, a scatter-type diagram was obtained in which a zone of heat damage is clearly indicated. Such a diagram should have practical value in research and commercial operations involving the heat treatment of rice, and it might, according to the method of derivation, serve as a heat-damage prediction chart for viability or milling quality.

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