

HIGH MOISTURE STORAGE OF ROUGH
RICE BY CONTROL OF
ENVIRONMENTAL GASES

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ABSTRACT

HIGH MOISTURE STORAGE OF ROUGH RICE BY CONTROL OF ENVIRONMENTAL GASES

by Dante B. de Padua

The feasibility of sealed storage for high moisture rough rice was determined on a laboratory scale. Combinations of 5%, 10%, and 20% initial concentration levels of oxygen with 0%, 30%, and 60% carbon dioxide were used with nitrogen as a filler. Viability, dry matter loss, and milling quality were evaluated using rice for 15, 30, 45, and 60-day storage. Comparative respiration rates were inferred from the final levels of carbon dioxide concentrations at the end of each storage period. The studies were made with 18%, 22%, and 26% moisture rice, of variety Nato, grown in Louisiana.

In all the sealed storage treatments, the grain remained clean, bright and free-flowing compared to the controls. The 18% moisture rice molded within 15 days. In the 22% and 26% moisture grain, the grain sprouted and severely molded within 15 days.

Oxygen was completely depleted in all treatments indicating purely anaerobic respiration beyond a 15-day storage period. There was, however, significantly higher rate of respiration in treatments where oxygen was initially available.

The germination after 60 days storage decreased significantly from 51% to 10% with increase in oxygen concentration from 5% to 20% in the treatments where the initial carbon dioxide concentration was 0%. In treatments where the initial carbon dioxide was 30% and 60%, the differences in germination between oxygen treatments were not significant, and the germination was preserved when the average germination of the six treatments dropped from 95% to 82% after 60 days of storage. In the treatments with 22% moisture content, there were no significant differences in the viability between treatments where average germination of nine treatments after 15 days was 28%.

Dry matter loss in the first 15 days was significantly higher in treatments with higher initial oxygen content. In all treatments, the dry matter loss increased significantly with storage time.

The milling quality of the rice at 18% moisture content in the various sealed storage treatments was not affected adversely in any way. At the 22% moisture, a slight odor in all treatments remained, at the 26% moisture a severe objectionable odor with about 30% heat damage was noted in all treatments. Small but significantly higher total milling yield was measured in treatments with higher initial oxygen levels with the highest yield in the treatment sealed with ordinary air. The over-all mean of all treatments up to 60 days in storage showed no significant drop in total yield

in the 18% moisture grain when compared to the control and reference samples. The over-all mean head yield of all treatments when compared with the control (0-day storage) showed no significant difference. The total and head milling yields showed small but highly significant increase with storage time.

Sealed storage of rice intended for human consumption is feasible at 18% moisture content for periods up to the 60 days investigated.

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HIGH MOISTURE STORAGE OF ROUGH RICE
BY CONTROL OF ENVIRONMENTAL GASES

By

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This dissertation is dedicated to my wife Ning, and children Liza, Duffy, and John David who was born in the midst of this venture.

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1. INTRODUCTION

Rice is the traditional food of a large portion of the world. Ironically, however, in many areas where rice is the staple food, technology in the production and processing has not kept pace with population increases. The Food and Agriculture Organization of the United Nations (FAO) estimates the need of increasing world production annually by at least 1.3 million metric tons of milled rice. An engineering aspect of the overall effort to increase rice production is the development of processes by which maximum yield of milled rice can be obtained from the grain already produced. Inadequate facilities in storing and processing the harvested grain has caused tremendous losses. An FAO report (1948) indicates that more than 10 million tons of rice are lost annually through improper methods of storage and processing.

The rice crop is normally harvested when its moisture content is much above safe storage levels. The grain is then cleaned, dried, and stored in bags or in open silos. Although rice is largely consumed in its milled and polished form of whole kernels, it has poor keeping qualities and is not stored as such for prolonged periods. Maintaining the rough rice in a dried state is recognized as the key factor in successful storage in open silos.

Dried rice grain absorbs moisture from humid atmospheres due to its hygroscopic nature. In many of the tropical climates where much of the rice is grown and consumed, a humid atmosphere causes much of the difficulty in the successful application of bulk storage in elevators. This inability to handle and store grain in bulk is seen as a limiting factor in the application of combine harvesting. The USDA Western Regional Laboratory, California (1955) reports that higher yields can be attained by harvesting the crop when its moisture content is above 26 per cent. But rice harvested in this wet condition deteriorates rapidly, so the interval between harvest and conditioning is important to maintain the quality of the grain. This deterioration of the grain is known to be principally controlled by moisture content, temperature, and oxygen supply. Hermetically sealed storage wherein the oxygen supply is reduced offers a possibility of storing rice in this relatively wet condition. Using a method of sealed storage such as developed for holding the wet grain even for short periods without appreciable deterioration, would facilitate early harvest and would put no limit on the amount of grain that could be harvested in a day. Grains intended for prolonged storage could then be dried on an extended schedule and perhaps more economically with smaller drying units.

The practice of storing grain in airtight containers is reported to have been tried in France as early as a century ago. Only in recent years, however, has airtight storage become a popular method of storing high moisture grain for feed purposes in the mid-Western parts of the United States. The advantages of airtight silos is causing widespread interest but the basic information for its use with high moisture rice intended for human consumption is not available.

2. OBJECTIVE OF THE EXPERIMENT

This experiment is based on the hypothesis that reduced oxygen atmospheres in the storage of rice inhibits metabolism of the grains, and of insects and molds, and as a consequence prevent heat generation and deterioration of quality of the grain. To achieve this purpose it is proposed to store freshly harvested rice in sealed storage systems. The objective of this experiment is to determine the feasibility of such a system of storing high moisture rough rice intended for milling in sealed storages. To evaluate the practicability of such a system, the influence of initially flooding a sealed storage container with different proportions of the main components of air, i.e., oxygen, carbon dioxide, and nitrogen, is measured in the milling index, dry matter loss, and viability of the rice grain. A measure of the respiratory activity of the grain under the different storage atmospheres is made by comparing the oxygen and carbon dioxide levels at the end of each storage period with the initial levels.

3. FUNDAMENTALS AND REVIEW OF LITERATURE

In undertaking this investigation the researcher familiarized himself with the physical structure of the rice kernel, its chemical composition, the physiological activity in storage of biological products, of seed grains in particular, and the processing standards of the rice industry. In formulating a proposal for this research project it was also necessary to review the literature on any investigation dealing with sealed storage.

3.1 Physical Structure of the Rice Grain

The physical structure of the rice kernel is composed primarily of the pericarp, the endosperm, and the germ. W. C. Dachtler (1958) describes the pericarp as several layers of cells which form a protective covering around the true seed. In the milling industry the pericarp is more commonly known as the rice husk or hull which has no value as human food. The hulls are structurally separated from the rest of the seed and their removal in the milling process does not cause the breakage of the other parts. The pericarp is not impervious to moisture. The moisture passes through the pericarp during the drying or rewetting process.

The endosperm is the major part of the seed and is composed of two parts. Dachtler (1958) calls the primary

part the starchy endosperm composed of brick shaped cells. The starchy endosperm is the edible part of the seed and may appear glutinous, non-glutinous, vitreous, pearly, or chalky depending on its structure. The second part is a thin layer of endosperm cell covering the starchy endosperm which contains oil and protein but no starch. This outer layer known as the aleurone layer or in the milling industry as the rice bran. The rice bran although high in nutritive value is not palatable and is removed during the scouring or polishing during the milling process. The milled rice with the bran left on does not keep well in storage because it tends to become rancid.

The germ is the reproductive structure which develops the rice plant through germination. It is a complicated structure and for this purpose it may suffice to quote Oxley (1948):

For the miller, germinative power is of no direct importance, but it is increasingly realized that germination is the most sensitive characteristic of grain and hence it is generally true to say that if germination is good, the grain is completely undamaged from the point of view of milling.

Oxley suggests germination test as a regular routine for millers. The germ contains unsaturated glyceride acids which favor rancidity. The germ is removed with the bran during the milling process.

3.2 Terminology and Standards Used in the Rice Industry

There seems to be a world-wide general agreement on the terminology used with reference to rice. Some of the more pertinent terms referred to in this paper will be defined here based on the United States Department of Agriculture Standards (USDA, 1961).

Rough rice--consists of 50 per cent or more of kernels of rice (*Oryza sativa*) from which the hulls have not been removed. In this paper rough rice is referred to unless otherwise specified.

Brown rice--consists of 50 per cent or more of kernels of rice (*Oryza sativa*) from which the hulls have been removed.

Milled rice--consists of whole or broken kernels of rice (*Oryza sativa*) from which the hulls and practically all of the germ and bran layers have been removed. A special grade of unpolished milled rice refers to that which only the outer bran layers and a part of the germ but not the inner bran layers, have been removed from the kernels.

Total milling yield--is an estimate of the quantity of whole and broken kernels of milled rice that can be produced from a unit of rough rice.

The milled rice is further classified according to size in the following manner:

Head rice--is the product of rice milling which, after the usual screening or sizing, consists of whole

kernels of milled rice and not more than 4% of broken kernels of milled rice which are not removed in such screening or sizing.

Broken kernels--consists of kernels of milled rice which are less than three-fourths of the length of the whole kernels, and split kernels of rice.

Second head rice--are broken kernels of milled rice which are between one-half to three-fourths of the whole kernels. (USDA defines head rice and the succeeding sizes by specifying the sizing plated used and gives in addition the percentage tolerance within each grade.)

Screenings--are broken kernels of milled rice which are between one-fourth to one-half of the whole kernels.

Brewers rice--are broken kernels of milled rice which are one-fourth or smaller of the whole kernels.

Chalky kernels--are kernels and pieces of kernels of rice each of which is one-half or more chalky.

Heat damaged kernels--are kernels and pieces of kernels which are materially discolored and damaged by heat.

The industry in the United States grades rough rice according to grade requirements based on criteria such as the presence of seeds and heat damaged kernels, red rice, chalky kernels, rice of contrasting classes, and rice of non-contrasting classes (varieties). Rice is given grade designations from U.S. No. 1 to 6, and Sample Grade. The designation U. S. Sample Grade is given to the rough rice

by USDA (1961) which,

. . . does not meet the requirements for any of the grades given from U.S. No. 1 to 6, inclusive, or which contains more than 18.0 percent moisture; or which is musty, or sour, or heating; or which has any commercially objectionable foreign odor; or which is otherwise of distinctly low quality.

A similar grading requirement and designation is given for milled rice. For milled rice the grading criteria includes the different types of broken kernels. U. S. Sample Grade for milled rice by USDA (1961) is given as,

. . . milled rice of any of these classes which does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 6, inclusive; or which contains more than 15.0 percent of moisture; or is musty, or sour, or heating; or which has any commercially objectionable foreign odor; or which contains more than 0.1 percent of foreign material; or which contains live or dead weevils or other insects, insect webbing, or insect refuse; or which is otherwise of distinctly low quality.

The milling yields (total, head and broken) in this paper are referred to the rough rice as a whole and are expressed as percentages by weight. The USDA determines the classes and grades of milled rice upon the basis of the milled rice.

3.3. The Rice Grain in Storage

One of the most desirable qualities of any agricultural product for human consumption depends on its ability to be stored in its almost fresh state with little or no loss in its nutritive quality. With the shortage of rice in many places, it is unlikely that storage requirements would

exceed one year. Rough rice can be stored easily under the correct conditions.

3.3.1 Physical properties affecting storage

The moisture content of the rice grain is considered the most important physical property of grain in storage. The rice seed with the moisture content below 13.5% wet basis, is relatively dormant. The rice grain maintained in this dry condition protected from insects and rodents, and with proper aeration to prevent spontaneous heating is the basis of commercial bulk storage systems in the United States. Adoption of these storage practice in other places with hot humid climates must be considered carefully. Rice like any other grain or hygroscopic material, gains or loses moisture when the vapor pressure of water in the space surrounding the grain is greater or less than the vapor pressure exerted by the moisture within the grain. M. L. Karon and M. E. Adams (1949) reported that the equilibrium moisture content of field-dried rough rice of 16.8% initial moisture content to be 13.2% at 70% relative humidity and 14.8% at 80% relative humidity. Rough rice which had been artificially dried to 12.8% moisture content level, has equilibrium moisture contents of 12.6% at 70% relative humidity and 13.8% at 80% relative humidities. This suggests one of the difficulties of storage in climates where the relative humidities is 80-90% most of the time.

Dachtler (1958) describes the moisture equilibrium as reached only after several weeks, but that the major portion of the moisture change occurs in a few days. Short periods of exposure to adverse storage conditions can produce marked changes in the moisture content. In general, for bulk storage a moisture content of 13.5% is suggested for periods less than six months and 12.0% for over a six month period.

Other physical properties found affecting quality in storage are the initial condition of grain, and the environmental conditions under which the crops were grown.

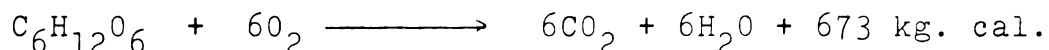
3.3.2 Physiological activity of rice grain in storage

Clean dry rice stored at a recognized safe moisture content (13.5%) may spoil in storage from the products of respiration, a natural process for all living grains (Dachtler, 1958). That the rice grain in storage is a live, respiring biological product is a phenomena of utmost importance often overlooked unknowingly in the engineering design and operation of grain storage systems.

The respiration process is externally manifested by a decrease in dry weight, absorption of oxygen, evolution of carbon dioxide, and liberation of energy in the form of heat. The gaseous exchange involving absorption of oxygen is called aerobic respiration since the process proceeds at the expense of atmospheric oxygen. Respiration where

carbon dioxide is evolved and oxygen is not absorbed but may occur in its presence is called anaerobic respiration.

The summary chemical equation for aerobic respiration is given by Meyer, et al. (1960) for hexose substrate as:



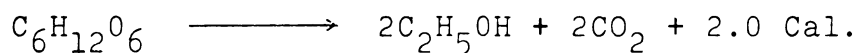
The rates of respiration for rice from measurements by C. H. Bailey are shown by Dachtler (1958). The milligrams of carbon dioxide evolved per day per one-hundred grams of dry matter increase with the increase in moisture content, in a logarithmic manner. Carbon dioxide evolved is shown as about 0.5 milligram per day per one-hundred grams dry matter at 13% moisture and about 18 milligrams per day per one-hundred grams dry matter at 17% moisture, at 100°F. The rate is reported to approximately double for each 20°F increase in temperature. The summary chemical equation thus shows that respiration in storage is a self-accelerating process since both the moisture and heat which are produced increase the process rate. Dachtler (1958) concludes that the carbon dioxide produced tends to reduce or modify the process if sufficient quantities can be accumulated but that additional information is needed on this phase of the process.

The oxidation of a hexose substrate is indicated by the summary equation as involving equimolar weights of gases absorbed and evolved. By Avogadro's hypothesis,

which states that equimolar weights of gases occupy the same volume, the volume of oxygen consumed is equal to the volume of carbon dioxide released.

The ratio of the volume of carbon dioxide released to the volume of oxygen absorbed in the respiratory process is termed the respiratory ratio or quotient. Complete oxidation of hexose substrate is shown as having a respiratory quotient = $\text{CO}_2/\text{O}_2 = 1$. Aerobic respiration where the substrate is principally carbohydrates is invariably reported to be approximately 1 (Meyer, 1960). Respiratory quotients in stored wheat of high moisture content where the oxygen supply is deficient may be as high as 8.8, indicating anaerobic respiration (Peterson, 1956).

Anaerobic respiration which occurs in or without the presence of oxygen takes place in every living cell. This process is involved in the fermentations by various species of microorganisms and fungi. Alcoholic fermentation produces carbon dioxide as one of the end products. The summary chemical equation for alcoholic fermentation is given as:



In experiments by Machacek (1961) where some of the grain (wheat, barley, oats) stored in closed jars, considerable pressure build up inside the jars was observed. Although not discussed in the text of the paper, this

would indicate anaerobic respiration where carbon dioxide is released without the corresponding absorption of oxygen.

The other external manifestation of respiration is the spontaneous heat generation. This phenomena is of serious consequence in bulk storage of grain, due to its porous, granular structure and its low thermal conductivity. In the absence of convective currents the grain mass practically insulates itself, and respiration process tends to cause a heat build-up resulting in heat-damaged grain. Oxley (1948) gives the thermal conductivity of wheat at 11.7% moisture content to be 1.05 BTU/hr.-sq.ft.-°F, comparable to that of dry soil (0.96). Steel has a conductivity of 26.5 BTU/hr.-sq.ft.-°F.

Heating in bulk stored grain is minimized by regularly turning the grain, i.e., transferring from one bin to the other through mechanical means and in the process aerating the grain. Other systems employ aeration systems where air is forced through the mass to remove the heat. Here again, this method must be used with caution in humid climates because of the danger of exposing the grain to wet air. McNeal (1957) recommends that the air for aeration should have a relative humidity below 60%. This means that in humid climates, to use an areation system, the air must first be dehumidified.

Aeration as a means of holding wet rice has been studied by various investigators. Dachtler (1958) reports

moving air through rice with moisture content from 18 to 24% has proved effective for periods of a week to ten days in preventing spoilage. Calderwood and Hutchison (1962) tried to determine the length of time wet rice (20.8% moisture) may be held in storage before some reduction in market quality takes place. Their samples were stored in bins equipped with aeration systems. In general, their results indicated a downgrade after nine to twenty-one days storage from No. 1 to No. 2 through No. 4. They found that higher airflow rates maintained the higher qualities which they attributed to a lower average rice temperature.

Oxley (1948) emphasizes that free access of the grain mass to air as in aeration of bulk stored grain is desirable only when the grain is hotter than the air so that it will lose heat, and damper than the air so that it will lose water. The benefits of ventilation in keeping temperature down can also be self-defeating. Aerobic respiration depends on a free supply of oxygen, and aeration drives out the accumulated carbon dioxide and provides ample supply of oxygen to support even higher rates of respiration and heating.

Where climatic conditions do not warrant the use of aeration in grain storage, the reverse policy of complete exclusion of free air is a possibility.

3.4 Various Storage Atmospheres as a Means of Inhibiting Respiration of Grain in Storage

The basic principle in sealed storage is the exclusion of outside air and limiting the supply of oxygen to inhibit aerobic respiration. This method should be differentiated from controlled atmosphere storage as in apples where the oxygen and carbon dioxide are maintained at optimum levels. Controlled atmosphere storage may be a superior process but may not be economically feasible for large volumes of grain. In sealed storage the oxygen in the interstitial atmosphere can be depleted biologically and the carbon dioxide allowed to build up to its equilibrium. It may also be done if found beneficial by flushing the original atmospheric air with inert gases, or gases with low levels of oxygen and high levels of carbon dioxide. The ideas of airtight storage are enumerated by Oxley (1948):

1. The carbon dioxide produced by respiration of grain and attendant organisms (including fungi and insects) will accumulate and oxygen depleted until all metabolic processes are brought to a standstill. This, it is suggested, will prevent heating, insect development and all kinds of deterioration.
2. Storage which is airtight is also proof against insects and rodents.
3. In damp climates uptake of water by drain dry grain from a moist atmosphere is prevented.

The most serious argument against sealed storage is that it fosters anaerobic respiration. Fermentation which is frequently an anaerobic process is reported to produce odors in the grain as well as damage to the viability of the grain. While this is indeed an objectionable result of

sealed storage, no information is available for rice on the extent of decrease in grade due to the odor or its milling quality, and the period before which any such damage may become predominant. The present availability of equipment for airtight storage and its popularity for storing high moisture feed grain increases speculation on the applicability of airtight storage for a limited length of storage of high moisture rice intended for milling.

Some investigations have been made to study the various factors influencing the behavior of grain in storage mostly with wheat, barley and oats under modified storage atmospheres. Meyer, et al. (1960) list the factors affecting the rate of aerobic respiration in plant cells as: (1) protoplasmic condition, (2) temperature, (3) food, (4) oxygen concentration, (5) carbon dioxide concentration, (6) hydration of the tissues, (7) light and certain chemical compounds. In respiration of grain in storage, temperature, oxygen and carbon dioxide concentration, hydration of the tissues (moisture content) are seen as the primary factors. Results of various researches with regards to these factors are reviewed here.

R. L. Glass (1959) reports that sound wheat with moisture content ranging from 13 to 18% in atmospheres of nitrogen and at temperatures of 20° and 30°C, was kept from deteriorating earlier than those stored in ordinary air atmospheres; that deterioration and nutritive changes were

much slower in the lower temperatures; that the viability of the grain stored in nitrogen remained fairly high even at 16% moisture content for 16 to 24 weeks. It was concluded in this study that at 30°C inert storage is not feasible for damp wheat, owing to a very active seed metabolism. At 20°C, however, the wheat enzymes were reported sufficiently inactive, so that together with the exclusion of mold growth by a nitrogen atmosphere, some benefits might be derived from this type of controlled atmosphere storage.

A. Peterson, et al. (1956) studied the influence of oxygen and carbon dioxide concentrations on mold growth and deterioration of 88% viable red spring wheat with moisture content of 18% and stored at 30°C in two kinds of gas mixtures.

One comprised mixtures of oxygen and nitrogen containing from 0.2 to 21.0% oxygen; the other containing 21.0% oxygen and varying quantities of carbon dioxide and nitrogen to provide carbon dioxide levels from 0.02 to 79% by volume. They report that after 16 days storage that mold growth, germ damage, fat acidity, and respiration rate are all gradually decreased as the oxygen concentration was lowered, but that a respiratory quotient of 8.8 indicated that anaerobic respiration was taking place as the oxygen concentration was lowered. The samples stored at 0.2% oxygen are reported to have maintained their viability whereas the samples stored in air were only 7% viable after 16 days.

They further found that in the presence of 21.0% oxygen, increasing levels of carbon dioxide had little effect on respiration rate until the concentration exceeded 13.8 to 18.6% when a very steep and marked inhibition of respiration, mold growth, and development of fat acidity occurred; and that at large concentrations of carbon dioxide of 50 to 79%, the viability of the wheat remained higher and that there was little or no germ damage.

D. J. Tennison (1954) stored high moisture rice (18 to 20% and 21.5 to 32.4%) in sealed glass bins for seven months in one trial and 34 days in another. Both sets became sour and lost viability. Simply sealing the bin and allowing the metabolic process to alter the atmosphere did not produce the desired storage conditions to prevent deterioration.

R. A. Bottomley (1950), in a study to determine the influence of various temperatures, humidities, and oxygen concentrations on mold growth and biochemical changes in stored yellow corn reports that although the variations in relative humidity was a controlling factor, lowering the oxygen concentration from 21 to 0.1% decreased the extent of the various changes.

Other organic chemicals have been tried to inhibit respiration. S. A. Matz (1951) suggests a 1:1 solution of propylene oxide and carbon tetrachloride; however, neither of these is reported to counteract the damaging effects

occurring in high moisture grain storage. Complete anaerobic condition was found to be more damaging than storage in an oxygen atmosphere.

C. C. Huxsoll (1961) found that moisture content or the water vapor pressure of the interstitial gases had the greatest effect on deterioration. The oxygen concentration of the gases is reported also to have had a pronounced effect, and that the carbon dioxide concentrations had little, if any, effect on the storage conditions.

An outright claim to an invention of a process for preserving rough rice under U. S. Patent #2,751,305 is made by S. A. Kaloyereas (1956). The process is claimed to preserve high moisture (20 to 30%) rough rice during prolonged storage from objectionable odor, color or flavor, loss of nutritional value, by placing the wet rice in a bin and maintaining it therein in an environment consisting of from 50 to 80 volume per cent of carbon dioxide and from 20 to 50 per cent by volume of air. The addition of small amounts of olefin oxide (0 to 0.1%), desirably ethylene oxide or propylene oxide, is recommended for prolonged storage of over six months, not only to kill microorganisms but is believed to have a catalytic effect on the desired action of carbon dioxide to reduce the life processes of rough rice. The process of injecting carbon dioxide into the atmosphere is to be repeated every six months to maintain the desired atmospheric composition. The exact

composition of the desired atmosphere is said to depend on the moisture content, atmospheric temperature conditions and the duration of storage.

An experiment on airtight storage of damp grain was performed using wheat and barley by Hyde and Oxley (1960). Grain of 17 to 24% stored both on a laboratory scale and in ten ton bins showed no mold development or heating even after prolonged storage. The grain was reported, however, to have developed a sour-sweet smell and taste which when extreme were not entirely removed by subsequent airing or drying. The rate of oxygen depletion and carbon dioxide increase was found to increase with moisture content and temperature of grain. Positive pressure was observed to have developed inside the containers for the grains of 16% and above; that as long as oxygen remained, the apparent respiration quotient was consistently 0.6 and 0.7 with all moisture contents; and that the change from aerobic to anaerobic was marked by a reduction in the rate of carbon dioxide produced.

Oxley (1948) was of the opinion that airtight storage cannot be recommended in any case where the water content may be high, but Hyde and Oxley (1960) suggests after further work in their laboratories that Tennisson's (1954) work showed poor results with high moisture rice and may have been due to leakage in Tennisson's containers. This is an encouraging indirect change of opinion on whether sealed storage could be used successfully for delaying or eliminating the need of artificial drying of high moisture grain.

4. DESIGN OF THE EXPERIMENT

This experiment was designed to be worked out on a laboratory scale using at least 2.000 kg of rice per sample for each treatment. A single variety (NATO) of rough rice obtained from the same batch was used.

4.1 Controlled Variables

The three main factors (moisture content, temperature, oxygen supply, and storage period) influencing storage quality of stored rice are controlled at the following levels:

1. Moisture content--two levels at 18% and 26% wet basis were initially proposed. Early data indicated the 26% moisture to be too wet and its use was, therefore, discontinued in favor of a new series at 22%.
2. Temperature--one level at $90 \pm 2^{\circ}\text{F}$ was used. This temperature reflects normal ambient conditions in tropical rice growing regions.
3. Oxygen supply--the oxygen supply for combustion normally comes from the interstitial grain atmosphere of which carbon dioxide and nitrogen are the two predominating components. Normal air has a volumetric composition of 21% oxygen

and 79% nitrogen plus small amounts of other inert gases. Under these normal conditions carbon dioxide level is only a fraction of one per cent. In the presence of respiring products and where there is no access to fresh air the carbon dioxide level of the atmosphere would rise to significant proportions. In order to evaluate the influence of oxygen supply and its possible interaction with carbon dioxide and nitrogen concentrations, nine combinations from three levels of oxygen (5%, 10%, 20%), three levels of carbon dioxide (0%, 30%, 60%), using nitrogen as a filler were used as initial storage atmospheres. The proportions of the three components are measured as percentages by volume.

4. Storage period--four storage periods of 15, 30, 45, and 60 days were scheduled. From preliminary investigations it was found impractical to hold the 22% moisture grain for extended periods. For this level, only two storage periods of 15 and 30 days was used.

Combinations of these factors comprise the controlled variables in this experiment and are referred to as treatments.

4.2 Observed Variables

The following variables which are a measure of the quality of the rice in storage were measured for each treatment.

1. Dry matter loss--was calculated from precise weighings of a 60 gram subsample. To calculate the amount of dry matter loss accurate measurements of the moisture content of the samples before and after the storage period were made from the 60 gram subsamples.
2. Viability--was measured from 100 kernels selected at random from a representative subsample of 60 grams.
3. Milling quality--was measured from 1500 grams of rice from each sample. The milling quality includes measurements of:
 - a. Total milling yield
 - b. Head yield
 - c. Broken kernels
 - (1) Second head
 - (2) Screenings
 - (3) Brewers rice
 - d. Heat damage
 - e. Bushel weight of rough rice
 - f. Subjective estimates of the odor of the grain after drying and milling.

4. Respiratory activity--this variable was inferred from the analysis of oxygen and carbon dioxide levels at the end of each storage period.

Each treatment condition was replicated three times to give three measurements of the observed variables. The following code was used to identify each treatment.

Example:

Moisure content-- 18%
 CO₂ level -- 0%
 O₂ level -- 20%
 Storage period -- 15 days
 Replication no.-- 1

This treatment is coded as (18 - 0 - 20 - 15 - 1) and is seen as a sample at 18% moisture content stored in a sealed container with an initial atmosphere of ordinary air composition, stored for 15 days and is No. 1 of three replicates.

4.3 Statistical Design

The analysis of the data to determine the influence of the controlled variables (treatments) on the observed variables is based on an analysis of variance on a two-way classification with three repeated measurements.

4.3.1 Hypothesis and assumptions

The analysis of variance or "the distribution of the measurements of a sample" is based on the assumption that

the samples are chosen from normally distributed populations of equal variance. Normally distributed population refers to the relative frequency with which a variable characteristic of the population is distributed according to a normal curve. The population in this experiment consists of all rice of variety Nato, grown under similar cultural environment, and of similar physical and chemical properties. Dixon and Massey (1957) state that the results of the analysis are changed very little by moderate violations of the assumptions of normal distribution and equal variance.

The statistical hypothesis is that the means of the measurements of a variable (viability, dry matter loss, etc.) for all treatments whose influence on the variable we wish to compare, are equal.

The level of significance, $\mathcal{L} = .01$, a 99% chance of accepting that the hypothesis is true, was decided upon as the basis for accepting or rejecting the hypothesis of equal means. The high level of significance was decided upon since it is a matter of serious concern to reject the hypothesis and to conclude that there is indeed an influence of the storage treatment.

The statistic F, the ratio of the mean square for treatment means to the mean square for within groups (within replicates) is used. A high dispersion of the treatment means compared to the dispersion of the samples from the same population would cause rejection of the hypothesis.

An $F(\nu_1, \nu_2)$ distribution for normally distributed populations of equal variance (C.R.C. Standard Mathematical Tables, 1959), where ν_1 = degrees of freedom for treatment means, ν_2 = degrees of freedom for within groups, is used.

The hypothesis is rejected if the computed $F_{\text{ratio}} > F_{1-\alpha}(\nu_1, \nu_2)$.

5. EXPERIMENTAL PROCEDURE

5.1 Equipment for Mixing Gases

5.1.1 Preparation of the gas proportions

The first step after establishing the experimental design was to design and build a device for preparing the different proportions of the three main components of air: oxygen, nitrogen, and carbon dioxide. Several methods were considered. One of which was to mix the gas components on a continuous flow process where each component would be metered (Huxsoll, 1961). Another was by batch mixing. It was calculated that about 2 cubic feet of gas mixture at 50 to 60 psi pressure would be required to flush the original atmosphere from the jars. It was obvious that batch mixing would be easier to control since it was necessary to provide only the initial gaseous atmosphere at the required ratios after which the jars would be sealed. The idea in batch mixing was to use liquid under pressure to flood a tank in a manner analogous to a piston in a cylinder. After completely flooding the tank and thus scrubbing the original gas in the tank the liquid would then be drained to calculated levels and pure components of the desired gas injected into the tank.

A steel cylindrical tank with welded seams similar to those used in household water heating systems was

secured. The tank 42 inches high and 12 inches in diameter has a capacity of over 2 cubic feet.

The mixing tank installed upright shown in Fig. 5.2 was fitted at the bottom with fittings and valves to allow introduction of fluid under pressure and for draining of the same. The top of the tank was also fitted with valves for introducing the gases. A separate outlet was provided at the top of the tank and fitted with a valve and a pressure regulator. A plastic tubing was arranged to provide a visual means of determining the water level in the tank. This sight glass was backed with a scale calibrated in hundredths of a cubic foot to indicate the space above the water level.

Ordinary tap water was tried as the flooding medium and was found satisfactory. Carbon dioxide and oxygen are known to be soluble in water to a certain extent and to minimize this error at first it was planned to saturate a certain volume of water with carbon dioxide and oxygen and recirculate the same fluid with a pump. However, after several calibration trials in mixing the gas using fresh water for every trial it was found that the amount of oxygen absorbed was negligible and that the carbon dioxide absorbed was sufficiently constant and could be compensated for in the calculations. A two per cent increase over the desired carbon dioxide level was found to compensate for the amount absorbed in all cases.

An attempt was made to utilize the oxygen normally present in the air in preparing the different gas mixtures called for in the experimental design. However, it was found difficult to consistently obtain the desired oxygen level at all times. The idea was discarded and oxygen together with other gases were bought in their relatively pure state in pressure tanks. The tanks were provided with single stage pressure regulators (Fig. 5.1).

The preparation of a gas mixture for a treatment will be illustrated with an example: Taking a 60% carbon dioxide, 20% oxygen, and 20% nitrogen mixture, a volume of two cubic feet at 50 psi is prepared. With a 2 cu. ft. volume there remains about ten inches of water above the drain pipe of the mixing tank to act as a seal. To compensate for carbon dioxide absorption by the water, 62% of the volume is actually used for calculation, i.e., $2 \times 0.62 = 1.24$ cu. ft. for carbon dioxide; $2 \times 0.20 = 0.40$ cu. ft. for oxygen; and $0.18 \times 2 = 0.36$ cu. ft. for nitrogen, making a total of 2.00 cu.ft.

The tank is first flooded completely, taking care that air bubbles are not trapped at the top of the tank, by allowing the water to drain from the top gas-outlet. The gas components are now ready to be introduced into the tank. Nitrogen is introduced first, followed by oxygen, and then carbon dioxide. This order is followed to minimize carbon dioxide absorption by the water since only a minimum amount of water is at the bottom of the tank by the time carbon dioxide is introduced.

The water level is lowered to the 0.36 cubic foot level and at the same time the nitrogen gas is introduced, to maintain positive pressure. When the 0.36 cubic foot level is reached nitrogen is allowed to build up to 50 psi pressure by means of the pressure regulator. The water level is then lowered further to the 0.76 cubic foot level ($.36 + .40$) while introducing oxygen. Again the oxygen pressure is allowed to 50 psi pressure. Finally the water level is lowered to the 2.0 cubic feet level at which time the carbon dioxide is introduced and allowed to build up to 50 psi pressure. The carbon dioxide gas as it comes from the high pressure supply tank is chilled due to expansion. It was not found necessary to compensate for this reexpansion as the carbon dioxide gas comes to room temperature in the mixing tank.

5.1.2 Analysis of the gas proportion

An Orsat Gas Analyzer by Hays Corporation was used to determine the accuracy of the proportion of the gas mixture. This type of gas analyzer which is more commonly used for analyzing flue gas could be read to the nearest half of one per cent by volume. The principle of operation consists in passing a measured volume of the gas sample in a burette at atmospheric pressure, first through a chamber containing potassium hydroxide. This chemical absorbs the carbon dioxide in the gas mixture, leaving all the other constituents unaffected. The gas is returned to the measuring

burette to determine the loss in volume representing the amount of carbon dioxide absorbed from the gas sample. The same gas sample is then forced through a chamber containing a solution of pyrogalllic acid in a solution of potassium hydroxide to absorb the oxygen. Again the sample is returned to the measuring burette to quantitatively measure the amount of oxygen absorbed. The remaining gas is taken as nitrogen.

Sampling of the gas is done by allowing the gas under pressure to flush the burette, or in cases where the pressure of the gas sample is low, it is aspirated through the burette. A water piston is used to force the gas into and out of the absorbing chambers from and to the burette. Appropriate needle valves are provided. While these are the chemicals commonly used, Hays Corporation provides chemicals for their gas analyzer under their own trade names with no indication of the actual chemical composition. Their chemicals are called "Zeez-O₂" for oxygen absorption, and "Cardizorber" for carbon dioxide absorption. A fresh charge of chemicals was always used whenever there was any sign of weakening as evidenced by having to repass the gas sample through the absorption chambers for complete absorption of either the carbon dioxide or the oxygen more than twice.

This same analyzer was used later in measuring the final gas composition in the storage jars when opened.

5.2 The Rice Grain Samples

There was not much choice in the variety of rice to be used for the experiment. It would have been ideal to use freshly harvested rice, but this was not feasible since the experiment had to be started in the early spring. Rice in the United States is normally harvested in the late summer to early fall. Rice is not grown in Michigan where this experiment was conducted and so the rice was purchased from Louisiana. Eleven hundred pounds of seed grain was purchased from the Public Drying and Storage, Inc. at Crowley, Louisiana, through the assistance of Dr. H. R. Caffey, Superintendent, and Mr. M. D. Faulkner, Assistant Professor in Agricultural Engineering of the Rice Experiment Station in Crowley, Louisiana. At this point, the researcher would like to acknowledge that the initial assistance for the purchase of rice was made by Mr. Jesse P. Perry, Fellowship Officer of the Rockefeller Foundation. Mr. Perry requested the assistance of Dr. Efferson, Dean of the College of Agriculture, Louisiana State University, who referred the request to the Rice Experiment Station at Crowley.

The eleven hundred pounds of rough rice was shipped in eleven one-hundred pound jute bags by rail. The whole batch appeared clean and uniform. The rice was tagged as of variety Nato, grown in Louisiana. Other pertinent information were given on the tags:

Pure seed -- 99.50%

Inert matter -- 0.20%

Crop seed -- 0.10%

Weed seed -- 0.20%

Minimum germination -- 80%

Hard seed -- None

Date of test -- December 1963

The rice was received in the first week of May. At the time there was no evidence of any insect infestation, however, three months later four bags left showed moth infestation. The extent of moth damage could not be determined. The bags of rice were kept at room temperature in the drying laboratory of the Agricultural Engineering Department prior to remoistening. Upon discovery of the moth in the grain, immediate steps were taken to clean the dry grain and store it at 40°F to suppress further moth development.

5.2.1 Remoistening of grain to predetermined moisture content levels

The grain was mixed by pouring part of each bag in several barrels. The barrels were then capped and rolled on the floor and mixed further by redistributing the contents of one barrel to the other barrels. The batch was randomly sampled and tested for moisture content. The moisture content averaged 12% (wet basis).

By experimenting it was found that 2.200 kilograms of rice of the 12% moisture rice was needed for each sample to

be stored in one gallon glass jars. This amount provided sufficient allowance for grain expansion as it absorbed moisture and just about filled the jar.

In the 18% and 26% moisture levels, twelve sample jars were required for each gas composition (treatment). In the later series of tests for the 22% moisture level, only six samples were required per treatment. It was an arduous job to wet the grain, with sets of twelve jars moistened daily. Moistening of the grain consisted of weighing out on a trip balance the least reading of which is 1 gram, 2.200 kilograms of rice. The dry grain was at 12% wet basis and 166 ml. of water was calculated to raise the moisture content level to 18% wet basis. Initial experimentation showed that a correction of +10 ml. was found necessary to take care of moisture lost to the atmosphere and adhering to the glass jars. Distilled water was used and measured in a glass cylinder to the nearest one milliliter and added to the grain in the jar. The jars were then capped and mixed by a combination of bouncing the jar on a two-inch foam rubber mat and shaking it on the rebound. After each thorough shaking, the jars were allowed to stand for thirty minutes after which they are again mixed. In four to six hours all the water was absorbed, i.e., no more free water would run down or collect at the bottom of the jar. At the end of the mixing period, the jars were then placed in a walk-in cold storage chamber maintained at 40°F.

The same ritual of rewetting for the other higher moisture levels was followed except that the shaking-mixing period took a longer time; 430 ml. of water was added to the 2.200 kilograms, 12% moisture grain to obtain a final moisture level of 26%; 292 ml. of water was required to produce 22%.

As mentioned earlier, it would have been ideal to use for the experiment freshly harvested high moisture grain. The main handicap of using remoistened grain is the cracking of the grain kernels during the rewetting process. This cracking of the grain when suddenly subjected to high humidity environment or immersed in standing water was confirmed in a thesis research work by Kunze (1964). Since the situation where having to remoisten the grain could not be avoided, milling property after storage is compared to a reference sample milled after being remoistened, tempered and redried without having been subjected to any storage treatment. A ratio of the milling property to that of the reference is referred to and used in this text as the milling index. Earlier initial experiments in rewetting of the grain by first humidifying the air by bubbling it through water and then through saturated salt solution to provide relative humidity equilibrium with the desired moisture content level was found impractical for the large volume of grain required. In this first attempt, it was hoped that by gradually increasing the moisture content in stages, the cracking could be minimized.

5.2.2 Moisture content determination

There are many methods for determining moisture content. Some researchers recommend with caution, grinding the sample due to moisture loss during the grinding process. Work done by M. L. Karon and M. E. Adams (1964) published in the FAO Bulletin 23 showed that it takes one-hundred and twenty hours for the whole grains at 101-103°C in forced draft oven, or whole grains at 99°C in a vacuum oven. Preliminary work verified that after 120 hours, there was no further significant loss in weight. It was decided to use a standard procedure of determining the moisture content of the samples by using 50-60 gram samples of whole kernels placed in 4½ oz. glass bottles dried in a vacuum oven. This oven is thermostatically controlled at 100°C as used for 120 hours (five days). These samples were weighed accurately on a Mettler balance which has an accuracy of ± 0.00005 gm., and which could be read to 1/10,000th of a gram. A single weighing bottle was used for all weighings. To minimize moisture-transfer, the bottles were capped with vaportight lids at all times outside of the oven, and the samples were always allowed to come to room temperature before weighing. This precaution was found necessary because of the high sensitivity of the balance. Gain or loss in moisture could be detected if the air was very humid and the samples cold in one case. Final calculations of moisture contents were carried, however, only to the thousandths.

5.3 Storage Containers

This experiment was designed to be done on a laboratory scale. By this is meant that measurements of the variable parameters would be from representative subsamples obtained from the main samples which consists of the entire treatment under controlled conditions as opposed to making measurements from samples randomly taken from a full-scale silo, for example. A minimum of two kilograms per sample was needed for making all the measurements required. One-gallon wide-mouthed jars held 2.200 kilograms of grain and were just suited for the experiment. Some 250 jars needed were gathered from all the cafeterias on campus.

5.3.1 Special jar caps

The caps of the 250 jars were all fitted with $\frac{1}{4}$ -inch copper tubing gas inlet and outlet (Fig. 5.4). One tubing for the gas inlet was soldered at the center and extended all the way down to $\frac{1}{2}$ -inch from the bottom of the jar. The outlet was a two-inch tubing soldered off-center and extending only $\frac{1}{4}$ -inch on the inside.

After several trials, it was found that in order to obtain a tight seal on the lids with the jars under pressure it was necessary to provide all the lids with special gaskets. Vellumoid gasket material, $\frac{3}{64}$ -inch thick was hand-cut to the size of the lids. During the sealing process, both sides of the gasket material were painted with sealing-wax.

5.3.2 Dry matter sample bags

The Mettler balance used in this experiment which had a high enough sensitivity has a maximum capacity of 200 grams. To use this balance for dry matter loss measurements it was necessary to enclose in a screen bag a subsample that would be buried in the grain mass within the jar. A 16-mesh-to-the-inch hardware cloth made of fiberglass was made into small bags (Fig. 5.3). This fiberglass material was chosen over other metallic screens to minimize errors due to possible corrosion. The seams of the bags were formed by heat-sealing. The bags were 13 cm. long x 6 cm. wide, and contained 60-65 grams of grain.

5.4 Preparation of the Samples for the Various Gas Treatments

All the rewetted grain samples in the glass jars were placed in the cold storage chamber maintained at 40°F within eight hours after the water was added. The wet grain sealed in the jars was left in the cold room to equilibrate from five to ten days. After storage the jars were removed for further preparation. As mentioned earlier, the samples were moistened in sets of twelve jars, and so the same sets of twelve jars were also brought out daily to be treated. The grain was allowed to warm up to room temperature (about 85°F) before opening. This prevented the water vapor from the humid air from condensing on the grain.

5.4.1 Final filling of jars, sub-sampling procedure, and sealing

For the 18% and 26% moisture series, the following procedure was followed. The grain from the twelve jars was dumped into a barrel and mixed thoroughly. Twelve screen mesh bags for dry matter loss measurements (DM bags, Fig. 5.3) were filled and the open ends heat-sealed. From the same batch of grain where the DM bags were filled, three 50-gram samples were obtained for initial moisture content tests. The filled DM bags were now carefully weighed in the Mettler balance. One DM bag was placed in each jar, after which the jar was again filled with grain. The precaution of keeping the DM bags buried in the grain mass after filling and before weighing was done to avoid moisture loss to the dry air.

It was found out later that when the jars were opened that there seemed to be more free moisture in the surface of the grains and that the screen bags appeared wet on the surface. This was especially so in the 26% moisture series. Because of this, a slight modification was followed in the procedure for dry matter loss measurements in the 22% series.

The set of samples for a treatment were brought out from the cold storage, dumped in a barrel, mixed and were immediately returned to the glass jars in equal amounts. The contents of the glass jar was then split four times for two sub-samples with the Boerner sample divider (Boerner divider further discussed in Sec. 5.5.4). In this case a

representative 50-60 gram sub-sample was used for initial moisture content determination of the grain in each jar. The other 50-60 gram sub-sample was placed in the DM bag and heat-sealed. This time the initial tare-weight of the DM bag was taken. The filled DM bag was then buried in the grain mass within the jar. This correction in procedure was hoped to give more data for more accurate calculation of dry matter loss. Increase in tare weight of the DM bags due to the adhesion of free water molecules could now be corrected for.

After filling the jars they were sealed with the special lids fitted with copper tubings. Each jar was then tested for seal by applying air under 10 psi pressure and immersing the whole jar in a tank of water. This was methodically done for each jar since it was found that the jars could easily develop a leak due to a faulty jar lip or a slightly dented jar cap. The 10 psi pressure was arbitrarily chosen and was found later on to be a good choice for most of the jars developed pressure in that range.

5.4.2 Flushing the jars and finally filling with the pre-mixed gases

With all the twelve jars tightly sealed, tested, and labeled, they were connected in series through their copper fittings by means of $\frac{1}{4}$ -inch rubber tubing. The outlet of one jar was connected to the inlet of the next jar, and so on (Fig. 5.5). Copper wire had to be wound around the

rubber tubing at the joints to maintain a tight seal under pressure. Tubing clamps were also provided for clamping the rubber tubing above the copper tubing later on.

One end of the series of bottles was connected to a vacuum gauge and the other end hooked on to a vacuum pump through an oil bubbler (Fig. 5.5). The oil bubbler was merely to protect the vacuum pump. When a vacuum of 15 to 20 inches of mercury was reached, the vacuum pump end of the series was clamped and the pre-mixed gas mixture was introduced at the other end at five pounds per square inch, until the jars were filled, as noted by the bulging caps. The jars were vacuum-pumped and refilled with gas for at least three times.

At the end of the third filling, the pressure in the mixing tank would have dropped from 50 to about 35 psi. This remaining gas was then allowed to continue flushing the jars, which took about half an hour with a pressure of 5 psi. At the end of this period, the gas exhausted from the jars was analyzed for the proportion of the three components with the Orsat gas analyzer. This was to make sure that the original atmosphere was completely flushed and replaced by the desired gas combination.

The rubber tubings were then clamped, cut, and tied over the copper tubing with copper wire (Fig. 5.4). Carbon dioxide is known to diffuse through the rubber tubing and so to minimize any carbon dioxide loss by diffusion, the

projecting copper tubings sealed with rubber tubings were then immersed in hot sealing-wax.

All the treated samples were then brought into a walk-in storage box with the temperature controlled at 90-95°F. The samples were left in the 90°F box until the time they were to be opened for analysis.

Preparing the set of twelve samples for a gas treatment, flushing them with gas, and sealing took most of ten hours.

5.5 Opening of Samples

5.5.1 Pressure measurement

It was noticed that the lids of the jars were bulging with pressure developed inside the jars. Out of curiosity this pressure was measured with an ordinary pressure gauge. The pressure varied from as low as 3 psi to as high as 15 psi, but mostly around 8-10 psi. There were some lids that completely failed in which case there would be no pressure.

5.5.2 Gas analysis

All the gas inside the jars was needed for making a gas proportion analysis with the Orsat gas analyzer. The inlet tubing extending to the bottom was connected to the gas analyzer and the gas allowed to flush the burette of the analyzer. Gas left under normal atmospheric pressure would then be aspirated out. This final step was found

necessary to completely flush the burette. The gas analysis was described in Sec. 5.1.2.

5.5.3 Weighing the DM bags

After analyzing the gas, the lids were removed, and the DM bags dug out for immediate weighing. There seemed to be a lot more moisture on the surface at this time, and it was necessary to weigh the bags immediately. Because of the wet condition, it was found impossible for the balance to come to a steady state. The reading shifted slowly after coming to rest momentarily as the moisture evaporated and so in many cases only the third decimal place ($1/1,000$ of a gram) could be read. There are roughly sixty grams of grain in the DM bags, hence the accuracy of dry matter loss could be measured only to $1/1,000$ of 60 grams or 0.00167 per cent of a change in weight.

5.5.4 Final moisture content and germination tests

The grain samples in the jars were sub-sampled for final moisture content and germination tests. To obtain a representative sub-sample from each jar, the whole sample was split four times using the Boerner sample divider. The two kilograms of grain poured into the hopper flows through an orifice and over the surface of a cone where alternate pockets channel the grain into the two containers at the bottom. A sub-sample of 50 grams was tested for moisture content in the standard method described in Sec. 5.2.2.

The final moisture content measurement was needed for dry matter loss calculations. The other 50-gram sample was used for germination tests.

Germination tests were made from each sample. One-hundred kernels from the sub-sample obtained by the sample splitter were placed between two moist germination blotters 7 x 7 inches square (Fig. 5.7). The blotters were placed on an enamel tray inside a special germinating box kept at room temperature of 80-85°F. Care was taken in selecting the one-hundred kernels and arranging them on a 10 x 10 grid for easier counting. Only mechanically sound kernels were selected. Kernels whose hulls were obviously damaged were discarded.

The air in the research laboratory was dry on most days and it was necessary to moisten the blotters periodically. Previous trials indicated that the healthy grains would germinate to over an inch in seven days, and that kernels that did not germinate in seven days will not germinate even if kept in the moist blotter for fourteen days. It was then decided to use seven days as the standard, and all germination counts were done seven days after sowing in the blotter.

5.6 Preparation of Samples for Milling Tests

The remaining grain after sub-sampling for the other measurements was then prepared for shipment to the Rice

Experiment Station at Crowley, Louisiana for milling tests. Milling of the grain requires that its moisture content should be around 10-11% for maximum total and head yield, according to Umali, et al. (1956).

5.6.1 Drying of the grain

The samples were, therefore, dried in a small batch type dryer specially built for this purpose (Fig. 5.8). The dryer consisted of three trays, each tray containing a replicate of a treatment, which were seated on top of a small plenum chamber 12 x 18 x 30 inches. On one end of the chamber was a conical diffuser which was connected to a straight-blade 6-inch electric motor-driven blower. Electrical heaters were installed in a rectangular plywood duct fitted on the suction side of the blower. The drying air at the plenum chamber was thermostatically controlled at 105°F. This low drying temperature was deliberately chosen so that the grain would dry slowly and kernel damage during the drying process would be minimized. Room temperature was usually around 85°F and heating the air by 20°F would reduce the relative humidity of the drying air by approximately one-half of the initial value.

The 18% moisture grain would generally require three-and-a-half to four hours drying time to reduce the moisture to 10-11% level; the 22% moisture grain required four to four-and-a-half hours and the 26% moisture grain required

seven to seven-and-a-half hours. The dryer was provided with an automatic timer to cut off the fan and heater after the pre-set drying time. As it must be in all dryers, electric protective relays were also installed to cut off the heater in case of failure of the blower.

The blower delivered sufficient air to allow stacking three trays, one on top of the other, i.e., drying three treatments of three replicates each, or nine samples all at the same time. The grain was about two inches deep in each tray.

Final moisture content was measured by a Steinlite moisture meter, model G.

5.6.2 Packaging of samples for shipping

The rice milling laboratory required 1500 grams of rice from each sample for complete milling analysis. This amount was weighed from the dried sample and sealed in 5 x 8 x .004 inches thick polyethylene bags (Fig. 5.9). The 1500 gram samples, sealed in "poly" bags, were then placed in cardboard boxes, crated and shipped to Louisiana for the milling analysis.

5.6.3 Analysis for milling property

The Rice Experiment Station at Crowley, Louisiana agreed to run a complete milling analysis of some two-hundred-twenty samples from this project without charge, in the interest of rice research. The milling analysis included determination of the following:

1. Total milling yield
2. Head yield
3. Second head yield
4. Screenings
5. Brewers
6. Per cent chalkiness
7. Per cent heat damage
8. Weight per bushel, and
9. Moisture content

The arrangement to send the samples to Louisiana was necessary since complete milling equipment for rice is not available at the laboratory here at Michigan State University. The complete testing procedure followed by the Rice Experiment Station is that described by W. D. Smith, Grain Division, AMS, USDA, of New Orleans, Louisiana in the Rice Journal, Vols. 58, Nos. 9, 10, 11, 12 (1955) issues. The testing procedure and equipment for the milling analysis will be briefly described here.

The first step in a milling quality test is a routine measurement of the moisture content. The Rice Experiment Station uses a MOTOMCO #909 moisture meter which is standard equipment at present for all offices of the Federal-State Grain Inspection Service.

The second test is the weight-per-bushel test to determine grain density. The procedure is quoted from W. D. Smith (1955) as follows:

At least $1\frac{1}{2}$ to $1\frac{3}{4}$ quarts of rice is poured into a funnel suspended two inches above a one-quart container. The funnel spout is opened and the rice flows through a $1\frac{1}{4}$ -inch diameter orifice into the quart container. The excess rice is struck off with three strokes of a special stick provided for this purpose. The container of rice is then weighed on a beam balance which is graduated in pounds per bushel. The standard test weight for rice is forty-five pounds per bushel.

The third step is to determine the straw weight. This test is done from a 1000 gram sample on a Carter Dockage Tester. This machine, with an air blast and a succession of sieves and riddles removes chaff, pieces of straw, etc. The rice used in this experiment was received clean. Obviously, it had previously been passed through a cleaning device. This third step was, therefore, omitted in the test at Louisiana.

The fourth step is the removal of the hulls or what is called the shelling procedure. United States Standards calls for the use of the McGill Sheller. The test is performed on a sample of 1000 grams. This laboratory device removes hulls and can be adjusted that no attritional pressure is exerted to remove the rice bran and also cause kernel breakage. The McGill Sheller operation is described by W. D. Smith (1955) in the Rice Journal. The machine has two rotating cylinders, one of rubber and the other of metal. The clearance between the two cylinders is to be accurately set for each variety of rice. Rice coming out of this machine is known as brown rice.

The fifth step in the milling analysis is to determine milling quality is the polishing or scouring process of the grain obtained from the sheller. Again, United States Standards call for the use of a standard laboratory McGill Miller. Details of operation is described by W. D. Smith (1955c). This device removes the bran and germs from the rice kernels by the attritional action of the kernels against each other and against a slotted semi-cylindrical screen mounted beneath a rotating ribbed cylinder. The cylinder is covered and through it a definite pressure by means of weights is applied to control the extent to which the kernels are pressed against each other and against the slotted screen. The scouring process is run for thirty seconds and is controlled by an automatic timer. After the thirty seconds, the mill is run for an additional thirty seconds during which the pressure is removed. During the entire process the weaker kernels in the sample are broken. The polished rice from this process is the total milling yield.

The sixth and final step is the grading process of the milled rice. In this the broken kernels are separated from the unbroken kernels (head rice). A sizing device developed by the USDA is described by W. D. Smith (1955d). The device employs plates with pockets or indents into which the different sizes of broken kernels fall are of a size which make, according to Smith (1955), "a sharp and

uniform separation." The grain is then separated with different sizing plates which is graded as Brewers rice, screenings, second head, and head rice. The weights of these grades are expressed as percentages of the original 1000 gram sample of rough rice.



Fig. 5.1--The three main components of air: CO_2 , N_2 , and O_2 were mixed in varying proportions and used as the storage atmosphere in a sealed storage system.



Fig. 5.2--The gas proportions were prepared in a batch mixing tank using water to flood the tank to obtain the different volumes required.

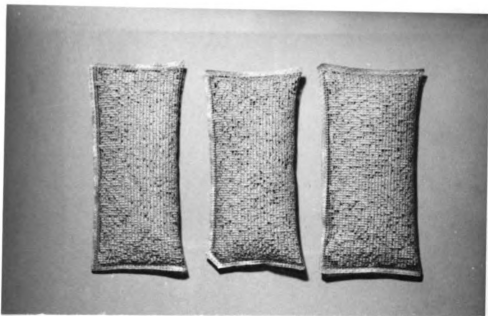


Fig. 5.3--Subsamples of about 60 grams from each main sample were enclosed in 16-inch mesh bags made of fiber glass. The bags were heat sealed at the seams. These subsamples were buried within the grain mass in the sealed gallon jars and were weighed before and after storage for dry matter loss.



Fig. 5.4--The high moisture grain were stored in hermetically sealed one gallon glass jars whose caps were provided with $3/64$ -inch gasket material treated with sealing wax. The caps were fitted with $1/4$ -inch copper tubings for introducing the storage gas. The copper tubings were later sealed with rubber tubings and dipped in sealing wax to prevent selective diffusion of carbon dioxide gas.



Fig. 5.5--The sealed jars were connected in series through the copper tubings with rubber tubing and the original atmosphere sucked out with a vacuum pump.



Fig. 5.6--An over-all view of the equipment and materials used in the investigation.

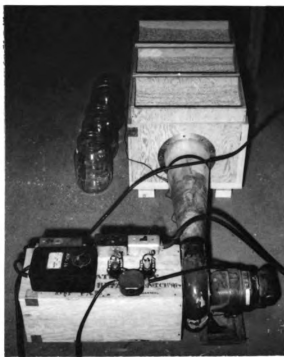
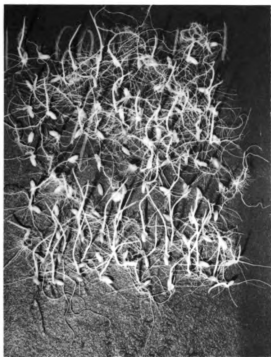


Fig. 5.7 (left) One-hundred kernels from a treatment were tested for viability on germinating blotters. Sample stored with 60% carbon dioxide, 5% oxygen for 15 days are shown after 7 days in the blotter.

Fig. 5.8 (right) The high moisture rice samples after the storage periods were dried in a small electrically heated dryer at 105°F prior to shipment to the milling laboratory.



Fig. 5.9--One-and-one-half kilograms of the dried grain from each treatment were sealed in polyethylene bags for shipment to the Rice Experiment Station at Crowley, Louisiana for analysis of milling quality.

6. DISCUSSION AND RESULTS

6.1 Respiration of the Grain

Quantitative estimates of respiration rate can be made by the determination of the end products of the reaction. Carbon dioxide evolution as shown in the summary equation for aerobic respiration and alcoholic fermentation (Sec. 3.3.2) lends itself to easier measurement and has been used as the index of respiration (Bailey, 1918). Milner (1954) pointed out, however, that due to the many external and internal conditions which affect oxygen consumption and carbon dioxide evolution, neither can serve as an absolutely accurate index of respiration. In view of this, the final carbon dioxide concentrations measured in this experiment are not used as the basis for comparing respiration rates of other grains under different environmental conditions. They serve, however, in this experiment as a comparative index for evaluating the influence of the various storage treatments. This is possible since the grain may be considered homogeneous, and the other external factors such as temperature and moisture content are controlled.

6.1.1 General physical appearance of the grain

All the rice samples stored in the sealed jars under the different storage treatments maintained their physical

appearance throughout the longest storage period of 60 days. The grain remained clean and free flowing. There was no mold development, even in the samples whose seals were broken by the high pressures and were leaking but not completely open. In comparison, the controls--rice stored in the jars but not sealed--deteriorated very quickly (Fig. 6.1, 6.2). At the 18% moisture level, the grain was severely molded within 15 days. At the 22% and 26% moisture levels, the grain molded, sprouted and was hot within 15 days in storage.

In general a slight fermented smell was detected in the rice at 18% moisture level. This smell was almost wholly removed after drying even for the grain stored for 60 days. Reports from the milling laboratory do not indicate any objectionable odor at the 18% moisture level. The sweet fermented smell was much more evident in the rice stored at the higher moisture levels of 22% and 26%. This odor remained after drying and milling. The rice at 26% moisture was reported by the milling laboratory as having objectionable odor.

6.1.2 Oxygen concentrations

In the three moisture content levels of 18, 22, and 26%, for all the storage treatments (various proportions of oxygen and carbon dioxide), after 15 days no oxygen was measured in the grain atmosphere. The exact period of



Fig. 6.1--Rice at 22% moisture content in sealed jars (B) remained clean and bright compared to the control (A) stored in open jars which sprouted and was severely molded within 15 days.



Fig. 6.2--From left to right are rice grain dried to 12% moisture, control sample stored in open jars (cap is perforated), and 26% moisture rice in sealed storage after 60 days.

complete oxygen depletion within the 15 days is not known. Even for the samples which had an initial oxygen concentration of 20%, within 15 days the grain respiration was entirely anaerobic.

6.1.3 The influence of different initial concentration levels of oxygen

The results of carbon dioxide concentration measurements of the grain storage atmosphere at the end of each storage period are plotted in Fig. 6.3 and 6.8. Within the first 15-day storage period higher total respiratory activity is evident in all treatments with higher initial oxygen concentrations. This is indicated by the higher total carbon dioxide evolved. A 10% difference in carbon dioxide concentration in the 18% moisture grain is noted between the 20% and 5% oxygen treatments after the first 15 days at all three carbon dioxide treatments of 0%, 30%, and 60% initial levels.

The same pattern is shown in the samples at 22% moisture content. The difference in carbon dioxide is lower, 4-5% between the 5% and 20% initial oxygen treatments. Plots of these data are the mean of three independent observations. The difference between treatments are obviously very significant, and no statistical verification was deemed necessary.

The differences between the carbon dioxide concentrations between oxygen treatments for a given initial carbon

dioxide level is primarily due to aerobic respiration. This is inferred from the slopes of the curves which indicates the rate of anaerobic respiration. The curves are almost parallel after the first 15 days in storage indicating essentially the same anaerobic respiration between oxygen treatments. But for comparing anaerobic respiration rates, merely observing the slopes is not quite satisfactory. The carbon dioxide evolved in purely anaerobic respiration was, therefore, calculated from the data using the following equation:

$$V_{CO_2} = \frac{1.817(\%CO_{2f} - \%CO_{2i} - \%O_{2i})}{(1 - \%CO_{2f})}$$

$$= \frac{1.817(\%N_{2i} - \%N_{2f})}{\%N_{2f}}$$

where V_{CO_2} = volume of CO_2 evolved in anaerobic respiration, liters per sample.

1.817 = voids in sealed jars, liters

subscript i = initial level

subscript f = final level

The volume of carbon dioxide evolved in anaerobic respiration expressed in milliliters per 100 grams of the 18% moisture grain is shown in Fig. 6.4. The differences between oxygen treatments at the 0% carbon dioxide treatment level and at the 30% and 60% levels were small and random. The curves are, therefore, shown as the mean of the oxygen treatments for the carbon dioxide levels indicated.

The influence of the oxygen treatments in anaerobic respiration which is the predominant activity in the sealed storage is negligible, but the curves on Fig. 6.4 shows that increasing the the initial carbon dioxide level does suppresses the anaerobic respiration.

6.1.4 Influence of different initial concentration levels of carbon dioxide

The curves in Fig. 6.3 are regrouped and shown in Fig. 6.5, 6.6, and 6.7 for each oxygen treatment so that the influence of the three carbon dioxide treatments may be studied. The curves are now shown as per cent increase in carbon dioxide concentration from the initial level. The plots show very distinctly the beneficial influence of carbon dioxide accumulation in the grain storage atmosphere on the respiratory activity. The curves for the 30% and 60% carbon dioxide treatments flattens out very shortly after 15 days as compared to the 0% carbon dioxide treatment, indicating comparative inhibition of the metabolic process. A net increase in carbon dioxide concentration of 60% at the 5% initial oxygen level, 18% moisture, is noted after 60 days for the treatment with 0% initial carbon dioxide level, a net increase of 31% or a 60-day level of 61% with 30% initial carbon dioxide level, and a net increase of 22.5% or a 60-day level of 87.5% with 60% initial carbon dioxide level. These carbon dioxide levels are generally higher by about 10% in the samples with initial oxygen levels of 20%.

At the 22% moisture level, 5% initial oxygen level, 0% initial carbon dioxide level, the carbon dioxide concentration rose to a high 65% within 15 days compared to only 26% in the corresponding gas treatment at 18% moisture content level. Final levels of 93% carbon dioxide concentration was measured for the 22% moisture content sample with initial gases of 20% oxygen and 60% carbon dioxide. This high level reassures the tightness of the seal, and the effectiveness of the sealing wax in preventing selective diffusion by the carbon dioxide gas.

In a few cases where the seals were leaking, as evidenced by low pressures, the gas analysis indicated approximately the same concentrations of the gas components compared to the other replicates.

These results provide a strong argument in favor of sealed storage where carbon dioxide is allowed to accumulate and supports the contention of Bailey (1918) that stored grain should not be disturbed as long as its temperature does not exceed that of the atmosphere. Exposing or ventilation would remove carbon dioxide, provide oxygen supply, and increase respiration rates.

6.2 Germination

Bailey and Gurjar (1918) believed that the germ or embryo of the wheat kernel is the location of the larger part of the biological respiration incidental to respiration, mainly due to the fact that the germ is richer in enzymes

than the endosperm. Bailey (1920) compared the respiration rates of the rice kernel at different stages of milling. Rough rice respired about three times more carbon dioxide than the milled rice which has most of the bran and germ removed; and brown rice which has hulls and part of the germ removed had about two times more carbon dioxide respired than the milled rice. In sealed grain storage, therefore, where respiration is the primary cause of spoilage, germination as proposed by Oxley (1948) is an important measure of the quality of the grain. But because of the fact that the respiration activity of the germ is many times greater than that of the endosperm, loss of germination does not necessarily mean loss of the grain for the millers. It is emphasized that sealed storage is not proposed for grains intended for seed, but that germination tests in this experiment are used as an index of the different storage parameters.

6.2.1 Influence of initial oxygen and carbon dioxide concentrations on germination

Preliminary plot of the data from the 18% moisture content level suggested that the influence of initial oxygen concentration at 0% carbon dioxide initial level to be comparatively more distinct than at the 30% and 60% carbon dioxide levels. Fig. 6.9 shows the germination to have dropped to a low 11% with the samples sealed with ordinary air (20% oxygen) in 60 days, and to only 51% with

the samples sealed with a reduced oxygen level of 5%, both with an initial carbon dioxide concentration of 0%.

Analysis of variance indicates these differences between treatments to be highly significant.

At the 30% and 60% carbon dioxide levels, plots of the points for the three oxygen levels were pretty much bunched-up although generally dropping with time. Analysis of variance provides evidence that difference between the three treatments at the 30% and 60% carbon dioxide levels not to be significant at the 1% level, but that the general drop in germination with time to be highly significant. In view of insignificant differences between treatments, the mean of the six treatments is plotted with time. As shown in Fig. 6.9, the germination dropped from 95% at the outset to 82% after 60 days in sealed storage.

This germination results again confirm the beneficial effect of high carbon dioxide concentrations in the grain storage atmosphere. This is in spite of an initial 20% oxygen concentration in two cases. This result is interesting in that in a regular sealed storage system, this investigation suggests that it is not necessary to artificially reduce the oxygen level, but that it is sufficient to merely introduce carbon dioxide gas into the grain atmosphere. This carbon dioxide gas may come conveniently from the exhaust of a furnace for heat exchangers in a related drying system.

At the 22% moisture level, there was no significant difference between the nine storage treatments even in the high carbon dioxide concentrations. The mean drop in germination was from 95% to 28% in 15 days. After 30 days germination was practically 0%. At the 26% moisture, there was no germination in 15 days.

Germination in the control (samples of the same moisture content but not sealed) dropped to 64% in 30 days at the 18% moisture content level. Beyond that the grain was severely molded and no further tests were made. At the 22% and 26% levels, the grain in the control jar sprouted and molded within 15 days (Fig. 6.1, 6.2) and no further tests were made.

Metabolic activity has been shown to increase with the degree of hydration. In this experiment, moisture contents above 18% indicates a respiratory activity much too high for the inhibitive effects of reduced oxygen and high carbon dioxide to be of value for extending storage life.

6.3 Dry Matter Loss

An attempt was made to carefully measure on a laboratory scale the amount of dry matter loss of rice in storage. The weights of the dry matter bags were carefully determined before and after the storage period, and moisture content determinations from representative sub-samples were made before and after storage. It was anticipated that there

would be a slight increase in the moisture caused by the metabolic water, one of the end products of respiration. Although extreme care was followed in sampling, weighing, and maintaining constant conditions in the vacuum oven, there was still considerable random variation in the results. Some of the measurements indicated loss and others a gain in moisture by as much as 0.1 of 1%. An analysis of variance indicated that these differences were purely experimental errors and, therefore, the mean moisture content before and after the storage period are within the limits of the precision of this experiment equal. In this connection, Meyer (1960) states that the water formed as a result of respiration becomes a part of the general mass of water present in the respiring cells and that it is seldom possible to measure experimentally the quantities of water released in respiration and the conclusion that water is an end-product of respiration is based largely on theoretical considerations.

There being no significantly measurable change in moisture content of the grain in sealed storage, the dry matter loss is calculated directly from the loss in weight of the grain in the dry matter bags. This loss in weight is presented as grams per 100 grams of moist grain.

6.3.1 Influence of oxygen on dry matter loss

At the 18% moisture level, the influence of the initial presence of oxygen is very pronounced at 0% and 30%

carbon dioxide levels as indicated by the results after the first 15-day storage period (Fig. 6.10). With 0% and 30% initial carbon dioxide concentrations and only 5% oxygen the drop in weight increases linearly with time starting from zero time. For the higher levels of oxygen (10% and 20%) for all three carbon dioxide treatments, after the first 15 days the drop in weight also increases linearly. It is noted that in the treatments with higher initial oxygen concentrations, the loss in weight is relatively higher than those with lower oxygen concentrations for the first 15-day storage period, but in the treatments with the higher oxygen concentrations the gradient after the 15 day period indicating loss in weight with time is less than those with lower oxygen levels.

In the treatments where the initial carbon dioxide level is raised to 60%, analysis of variance indicates no significant difference between treatments having 10% and 20% oxygen. The increase in dry matter loss with storage time is, however, highly significant. In cases where there are no significant differences between treatments, only the mean of the several treatments is plotted.

Dry matter loss measurements in the higher moisture levels of 22% and 26% had considerably higher variations between replicates and between treatments. This is attributed to the difficulty in making precise weighings of the dry matter sub-samples. There was much more free moisture at the

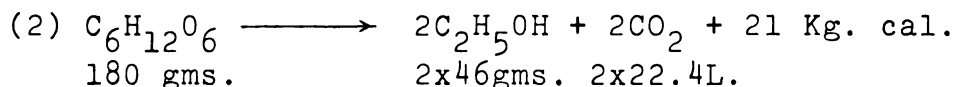
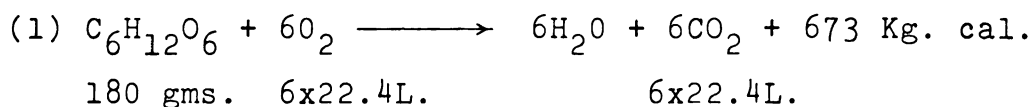
surface which evaporated readily in the dry atmosphere in the laboratory once the seals in the jars were broken. The loss in weight due to evaporation could be noted in the scale of the Mettler balance which was creeping constantly. These variations due to experimental error could have masked any differences between treatments. Analysis of variance shows no conclusive evidence between treatments although increase in dry matter loss with storage time is highly significant.

6.3.2 Influence of carbon dioxide on dry matter loss

The dry matter loss curves were regrouped for the same oxygen levels in order to determine the comparative influence of carbon dioxide. The bunching of the curves suggested analyzing the variance separately for each oxygen level. At the 5% initial oxygen level the inhibitive effect of carbon dioxide was highly significant. At the 10% and 20% initial oxygen levels, the analysis of variance showed evidence that the influence of carbon dioxide were no longer significant at the 1% level. The means, therefore, between the 10% and 20% oxygen treatments are the only ones shown in the curves on Fig. 6.9.

6.4 Some Theoretical Calculations

The summary chemical reactions in aerobic respiration and alcoholic fermentation, the two most likely processes in sealed storage of carbohydrates are the following (Milner, 1954):



The figure indicated below each organic compound is the molecular weight per mole and the gram molecular volume for the gas in liters.

From these chemical equations and the experimental data, some theoretical estimates were made.

Data:

Volume of storage jars = 1 gal. (3.785 liters)

Weight of rice in jars = 2.366 Kg. at 18% m.c.

Voids in rice = 48% (Hall, 1957)

$\therefore$ Space in storage jar = .48 x 3.785 = 1.817 liters

A sealed storage system is considered where the initial grain atmosphere is air (20% oxygen, 0% carbon dioxide, 80% nitrogen) at normal atmospheric pressure. Due to the metabolic process the carbon dioxide concentration reaches 63% in 60 days with the pressure increasing isothermally.

The amount of substrate burned is to be estimated.

Assuming a respiration quotient of one for the aerobic process, the carbon dioxide concentration would increase to 20% after all the original 20% oxygen is used in combustion. There should be no increase in pressure for the aerobic respiration. The 20% oxygen of the initial storage atmosphere converted to carbon dioxide, is (0.20 x 0.48 x 3.785), or

0.363 liters. From the chemical equation (1) one mole (180 gms.) of the substrate requires 6×22.4 liters of oxygen for complete reduction, therefore, the amount of substrate, X_1 , burned by 0.363 liters of oxygen is obtained from the proportion:

$$\frac{X_1}{180} = \frac{0.363}{6 \times 22.4} \quad ; \quad X_1 = 0.486 \text{ gms.}$$

The anaerobic respiration which may occur concurrently with the aerobic process or in the absence of oxygen is responsible for the increase in pressure. Assuming alcoholic fermentation as in chemical equation (2), the amount of further substrate loss due to this process is estimated.

With a final carbon dioxide concentration of 63% the volume of carbon dioxide evolved is calculated thus:

$$0.63 = \frac{V_{CO_2}}{V_{CO_2} + 1.817}$$

$$V_{CO_2} = \frac{0.63 \times 1.817}{0.37} = 3.094 \text{ liters}$$

$$\begin{aligned} \text{Carbon dioxide evolved by anaerobic process} &= 3.094 - 0.363 \\ &= 2.731 \text{ liters} \end{aligned}$$

From the chemical equation (2), substrate X_2 converted is:

$$\frac{X_2}{180} = \frac{2.731}{2 \times 22.4} \quad ; \quad X_2 = 10.973 \text{ gms.}$$

$$\begin{aligned} \text{Total substrate converted} &= X_1 + X_2 \\ &= 0.486 + 10.973 = 11.459 \text{ gms.} \end{aligned}$$

or,

Expressed per 100 gms. of the grain at 18% m.c.,

$$\text{Dry matter loss} = \frac{11.459 \times 100}{2366} = 0.484 \text{ gms./100 gms.}$$

The mean value of the measured dry matter loss with 20% initial oxygen level is 0.475 gm./100 gms. which comes out remarkably close to the theoretical calculations.

The 2.731 liters of carbon dioxide evolved anaerobically when compressed to 1.817 liters of space by Boyle's law would exert a pressure of:

$$P_2 = \frac{14.7 \times 2.731}{1.817} = 22.094 \text{ psia}$$

or

$$22.094 - 14.7 = 7.394 \text{ psi gauge}$$

The pressures measured for this treatment were around these values. The seals in the jars were tested at 10 psi.

6.5 Milling Quality

The milling property of the stored grain is the most important index of quality. The economic value of milled rice in general depends not only on the total milling yield but also on the amount of head yield and the absence of discoloration due to heat damage. In some rice-consuming areas however, high head rice does not command a premium price and, therefore, only total yields are of importance.

The milling property of the original rice as purchased at 12% moisture content, without remoistening, is referred

to here as the reference. Rice of variety Nato have total milling yields in the 70-74% range, and head yields in the 63-65% range (Faulkner, 1964).

The influence of the storage treatments on the milling property, for the different lengths of storage periods, are compared to control samples. The control samples were remoistened and tempered together with the other samples used in the experiment. After tempering in the cold storage chamber, however, they were not subjected to any form of storage treatment but were immediately dried to 12% moisture content and sent to the laboratory for milling analysis.

6.5.1 Total milling yield

The average total milling yields of the reference and control samples at 18% moisture content level, from three independent measurements each are equal, which is 71.8% of the original rough rice.

The total milling yields at 18% moisture content subjected to the different storage treatments remained comparably high with a range of 69.8% to 73.1% and an overall mean of 71.9%. Statistical comparison (Table 6.1.4) between the means of reference, control (0-day), and the storage treatments showed no significant difference. Analysis of variance to compare the means of the several treatments showed significant differences among the storage treatments and the storage periods (Table 6.1.3). An

examination of the data showed that the trend in the differences among treatments at the end of each storage period were the same and that the differences with the storage periods were very small but which were statistically significant at the 1% level. In view of this, and since it would serve no purpose to present the data graphically at the end of each storage period, the mean of the four storage periods (12 samples) for each treatment is presented in Fig. 6.10 as block diagrams. The mean of the eight storage treatments is shown for each storage period in Fig. 6.11. The variation among some of the treatments is only in the order of 1%, with total yield significantly higher in the treatment sealed with ordinary air. Treatments with 60% carbon dioxide appear to have higher total yields than the others. In general, there seems to be slightly higher yield with the higher initial oxygen concentrations.

The mean total yields at the end of each storage period shows a slight significant increase with time from a low of 71.4% after 15 days, and a high of 72.3% after 60 days. The control sample has a total yield of 71.8% in comparison.

This investigator is at a loss to explain this behavior among the treatments. It can only be speculated that an explanation may be with the physio-chemical transformation within the grain during storage.

With the 22% moisture grain, the same high total recoveries are obtained. The control sample (0-day) at 22% moisture content had a mean of 70.5%, and the storage treatments had a low of 70.9% and a high of 72.0%. A statistical comparison (Table 6.15, 6.16) of the differences among treatments, and between reference sample, control sample, and over-all mean of treatments, are statistically significant at the 1% level.

6.5.2 Head yields

The breakage in the grain was due to the remoistening process. This result was expected (Kunze, 1964). The head yield in the reference sample was a high 59.7% and the control sample was a low 8.2%. The over-all head yield of the storage treatments at 18% moisture content (96 samples) was 9.4% with a range of 4.3% to 24.9%. The analysis of variance (Table 6.18) indicated significant differences among the treatments and storage periods at the 1% level. The head yield is presented as a block diagram in Fig. 6.12 for the same reason as in total yields. The head yields are shown as the mean of the four storage periods (12 samples). The variation in head yield with storage period is shown in Fig. 6.13 as the mean of eight treatments (24 samples). There is not much difference in head yields in the storage treatments compared to the control sample except for the treatment sealed with ordinary air which has a head yield of 23.8%, or almost

three times that of the control. Statistically, the differences are significant, but the differences are small and random so that it can be said that the sealed storage system does not affect the head yield recovery adversely.

The variation in head yield with the storage period shows a slight increase with time but which levels off after the 45-day period.

With the 22% moisture content grain, the head yields were much more lower than those obtained from the 18% moisture grain. The control sample had a head yield of 2.6% and the treatments had an over-all mean of 2.8% with a range of 1.3% to 3.6%. Statistical analysis (Table 6.19) indicated that the differences among treatments and control sample (0-day) are not significant at the 1% level.

6.5.3 Broken grains

The difference between the total yield and the head yield constitute the brokens which are further classified in the analysis into second head, screenings, and brewer's rice. The distribution of the broken grains in these three categories for the 18% moisture grain are shown in Fig 6.14. The treatments are comparable to the control which has a second head yield of 28%, screenings--27.4%, and brewers--8.2%. The over-all mean for the treatments (96 samples) at 18% moisture content are: second head yield of 25.8%, screenings--27.9%, and brewers--8.7%. Fig. 6.14 shows that in general, the treatments that have higher total and head

yields have lower brewer's rice. This indicates that the loss in yield is due to the very finely broken grains probably carried away in this milling process with the bran and hulls.

6.5.4 Heat damage and bushel weight

No heat damage was reported by the milling laboratory of the samples in the 18% and 22% moisture levels. The treatments in the 26% moisture level had heat damaged grain in the order of 30%.

Bushel weights of the samples at 18% and 22% moisture level were essentially the same as the reference sample at 47.0 lbs. The 26% moisture level treatments had markedly reduced weights in the order of 45 lbs. per bushel.

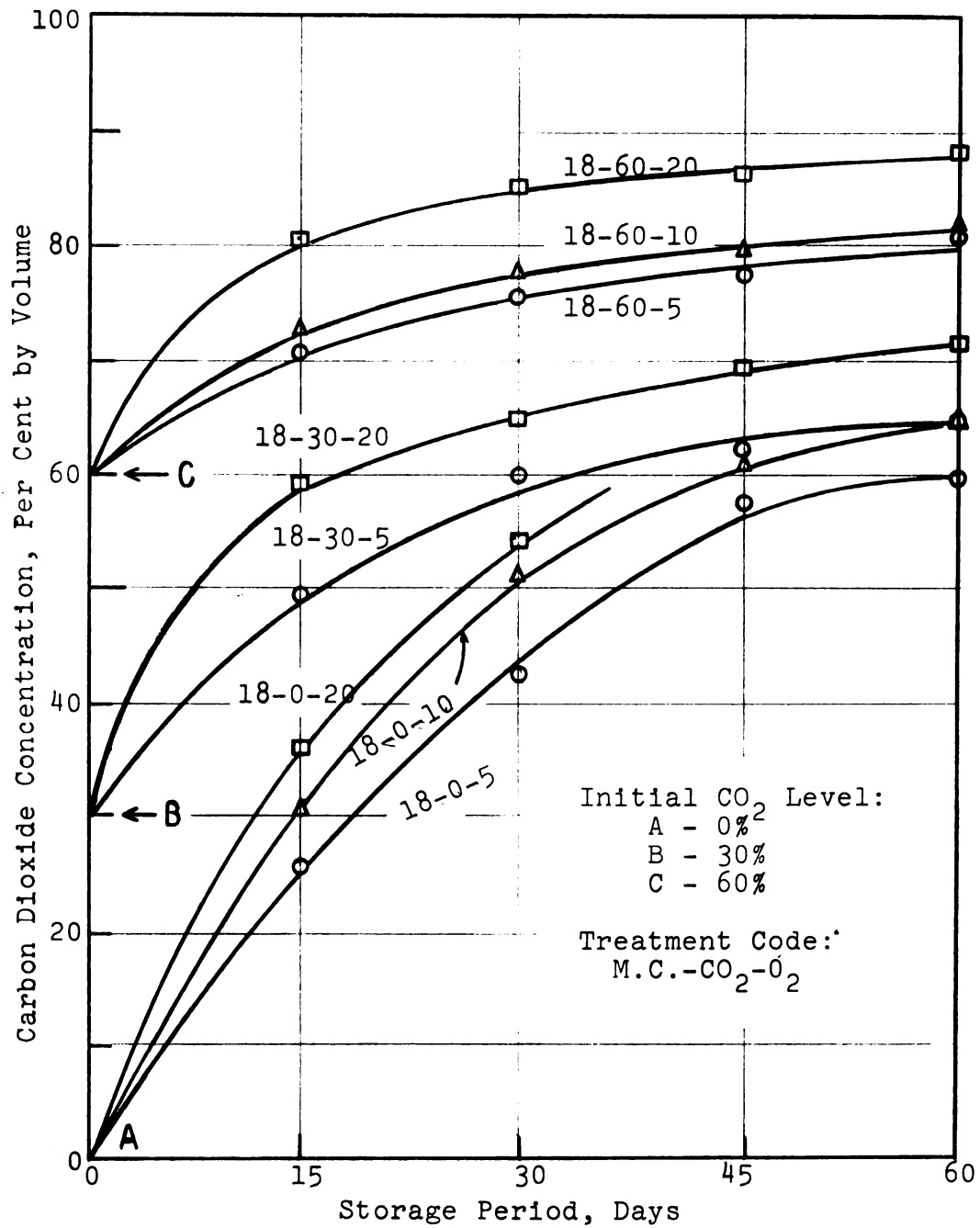


Fig. 6.3. Carbon dioxide concentration build-up in the grain storage atmosphere for rice at 18% moisture content, in a sealed storage container.

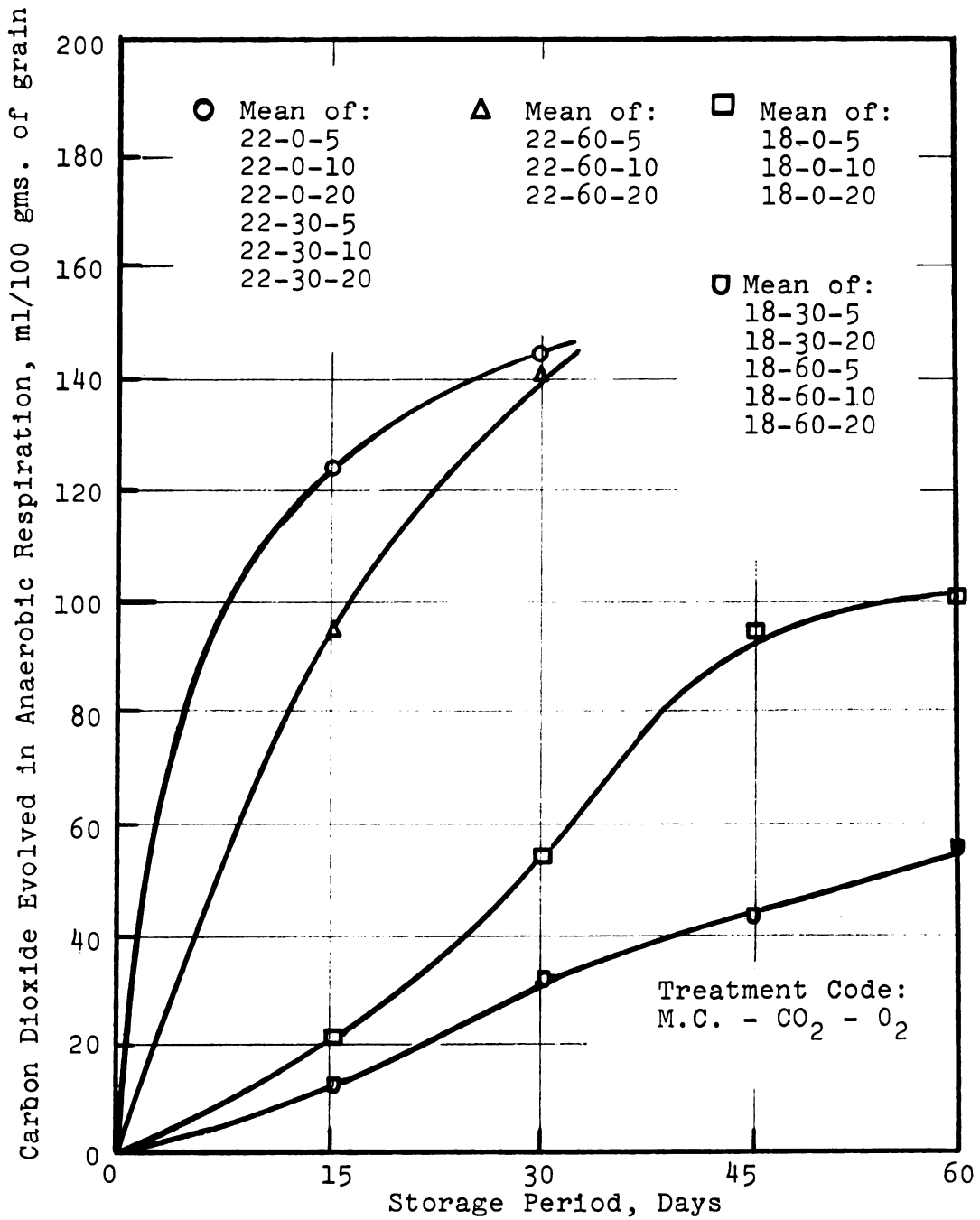


Fig. 6.4 Carbon dioxide evolved in anaerobic respiration for rice at 18% and 22% moisture content.

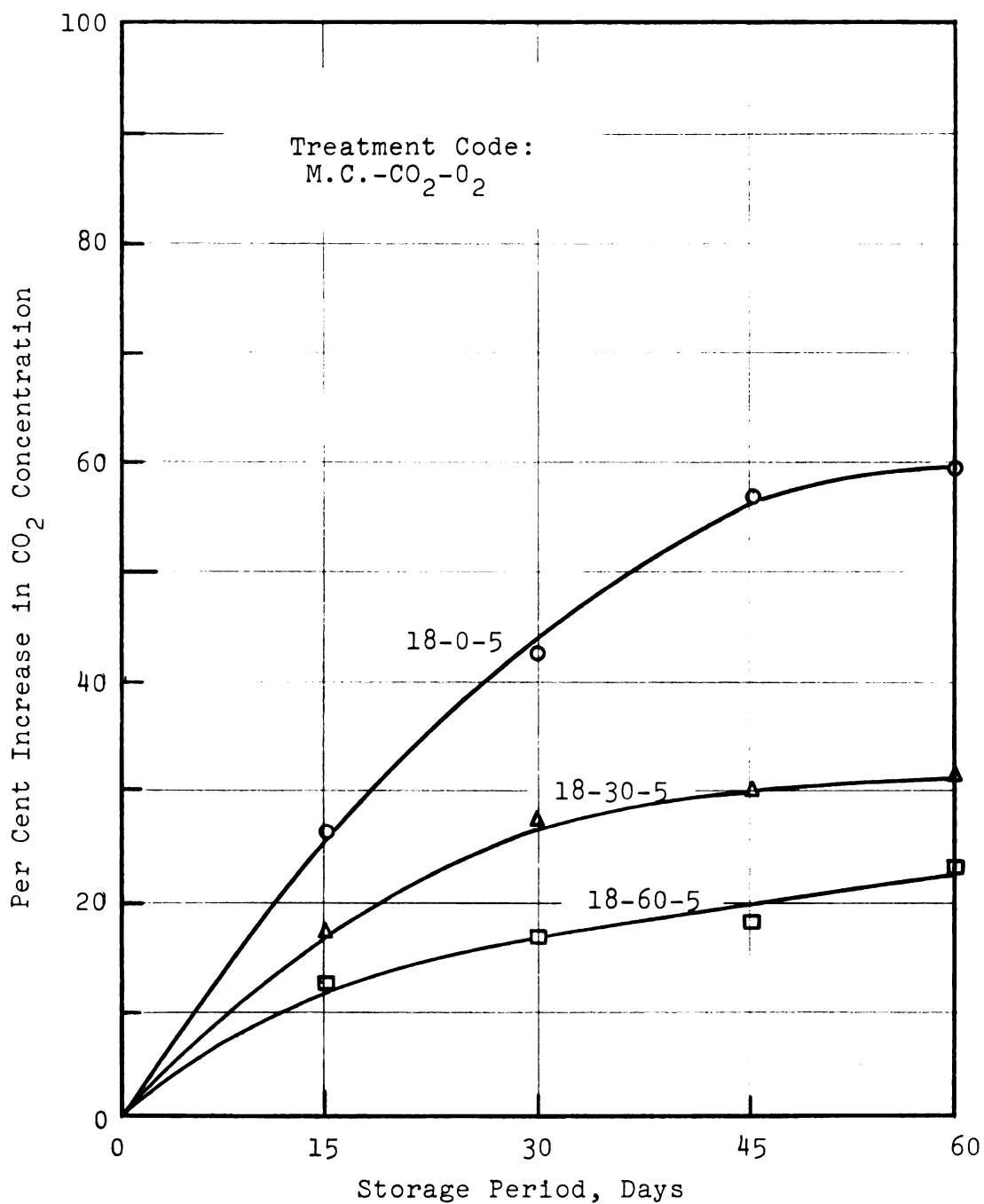


Fig. 6.5. Comparative increase in carbon dioxide concentration for different values of initial carbon dioxide levels with 5% initial oxygen level.

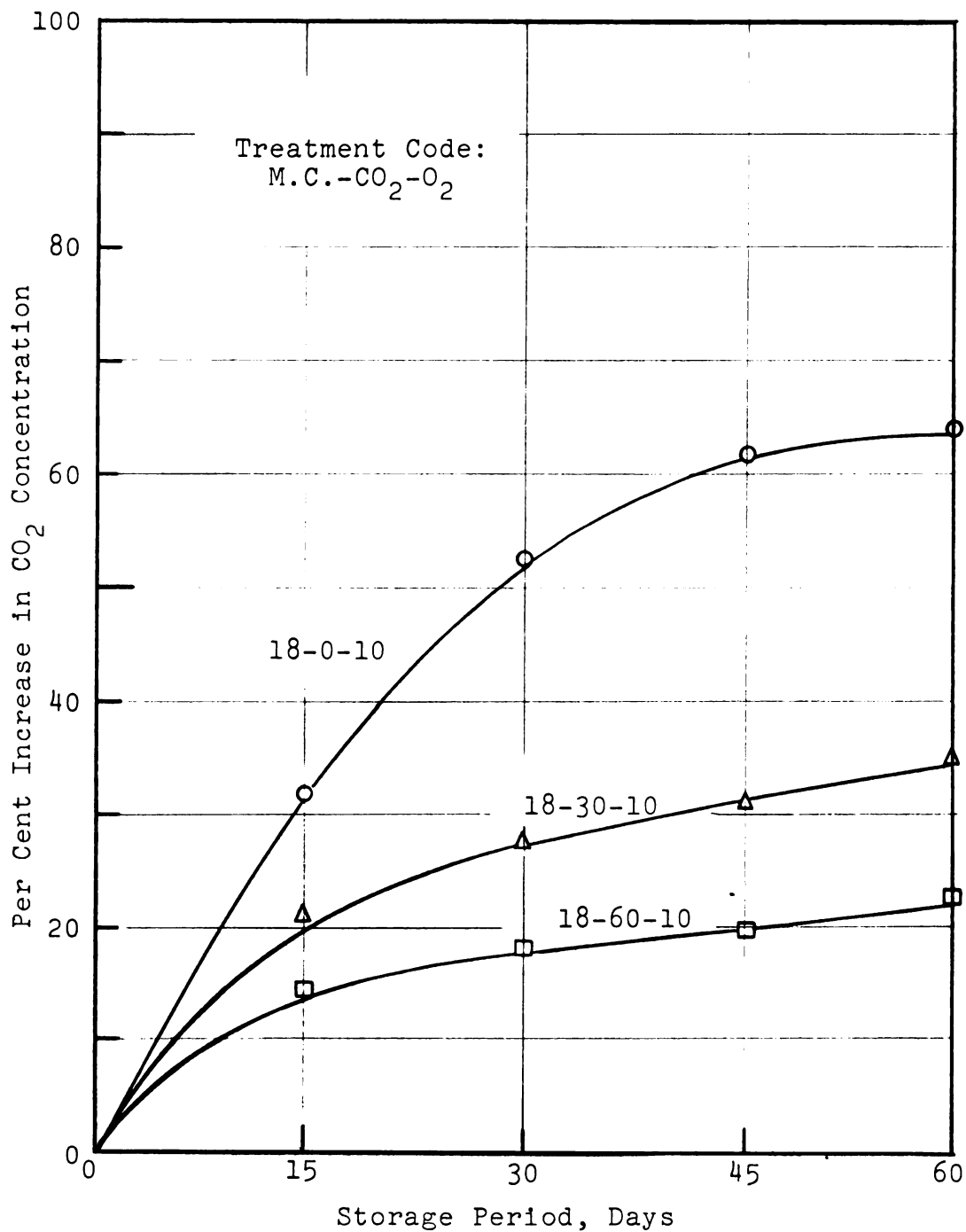


Fig. 6.6. Comparative increase in carbon dioxide concentration for different values of initial carbon dioxide level with 10% initial oxygen level.

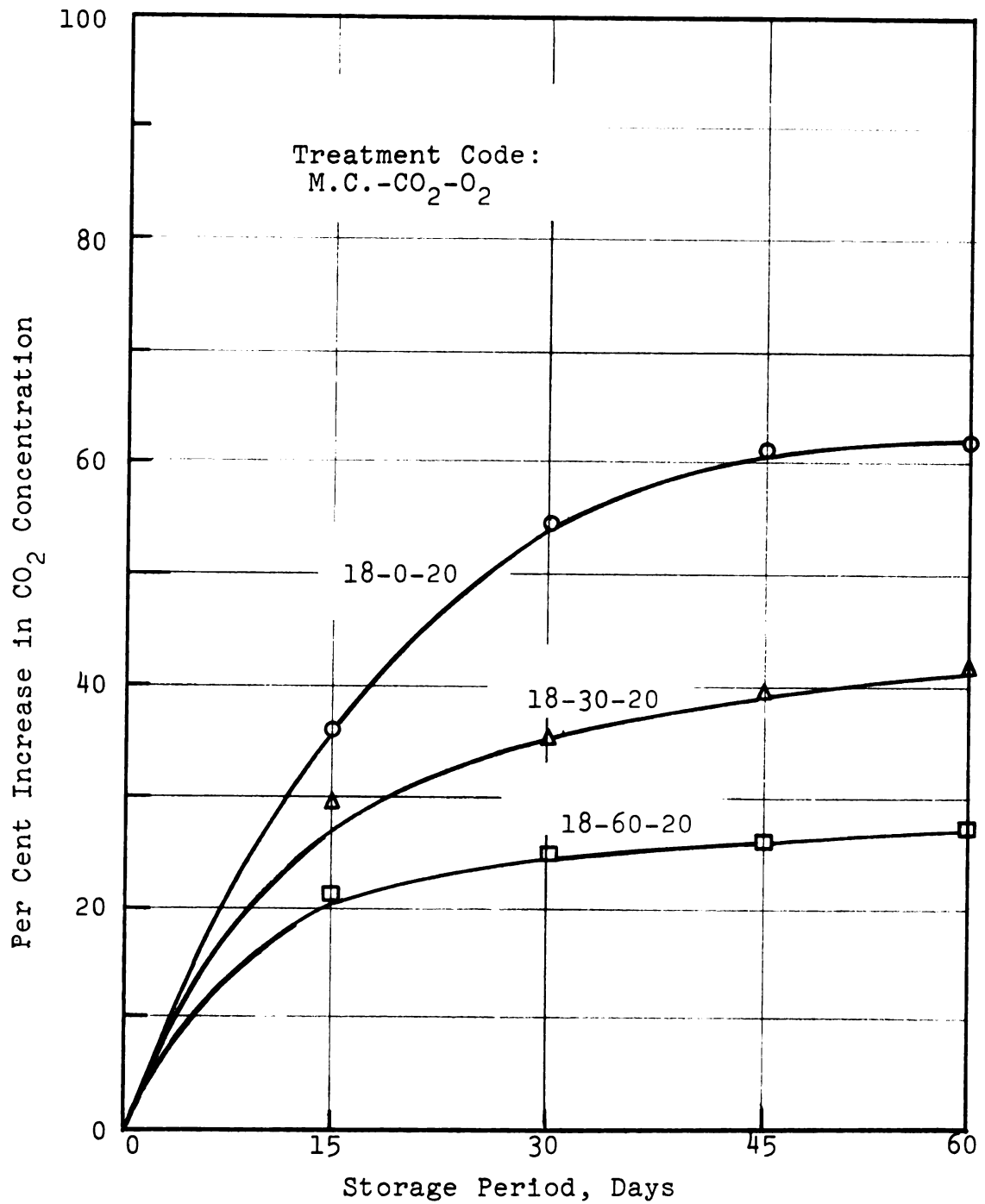


Fig. 6.7. Comparative increase in carbon dioxide concentration for different values of initial carbon dioxide level with 20% initial oxygen level.

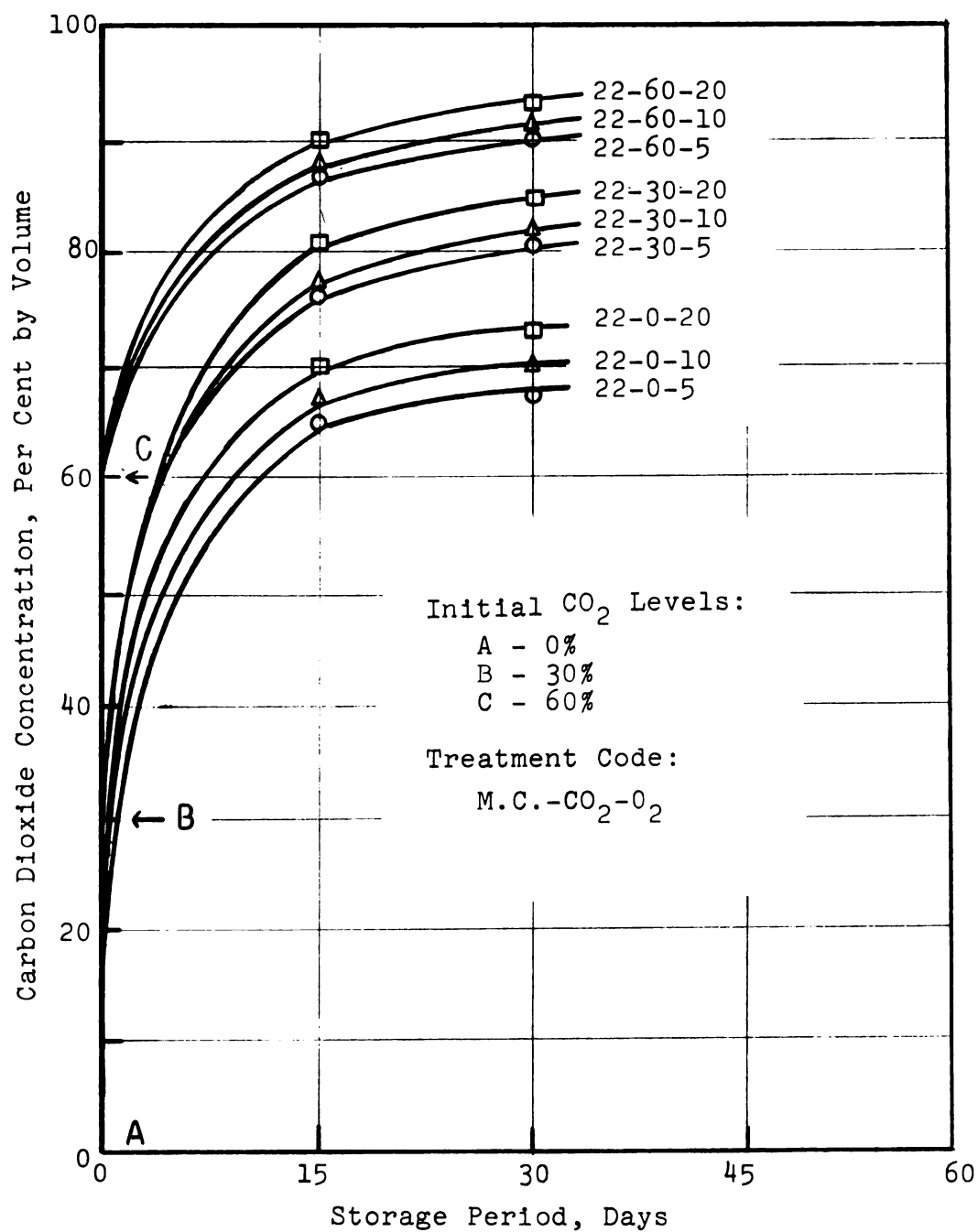


Fig. 6.8. Carbon dioxide concentration build-up in the grain storage atmosphere for rice at 22% moisture content in a sealed storage container.

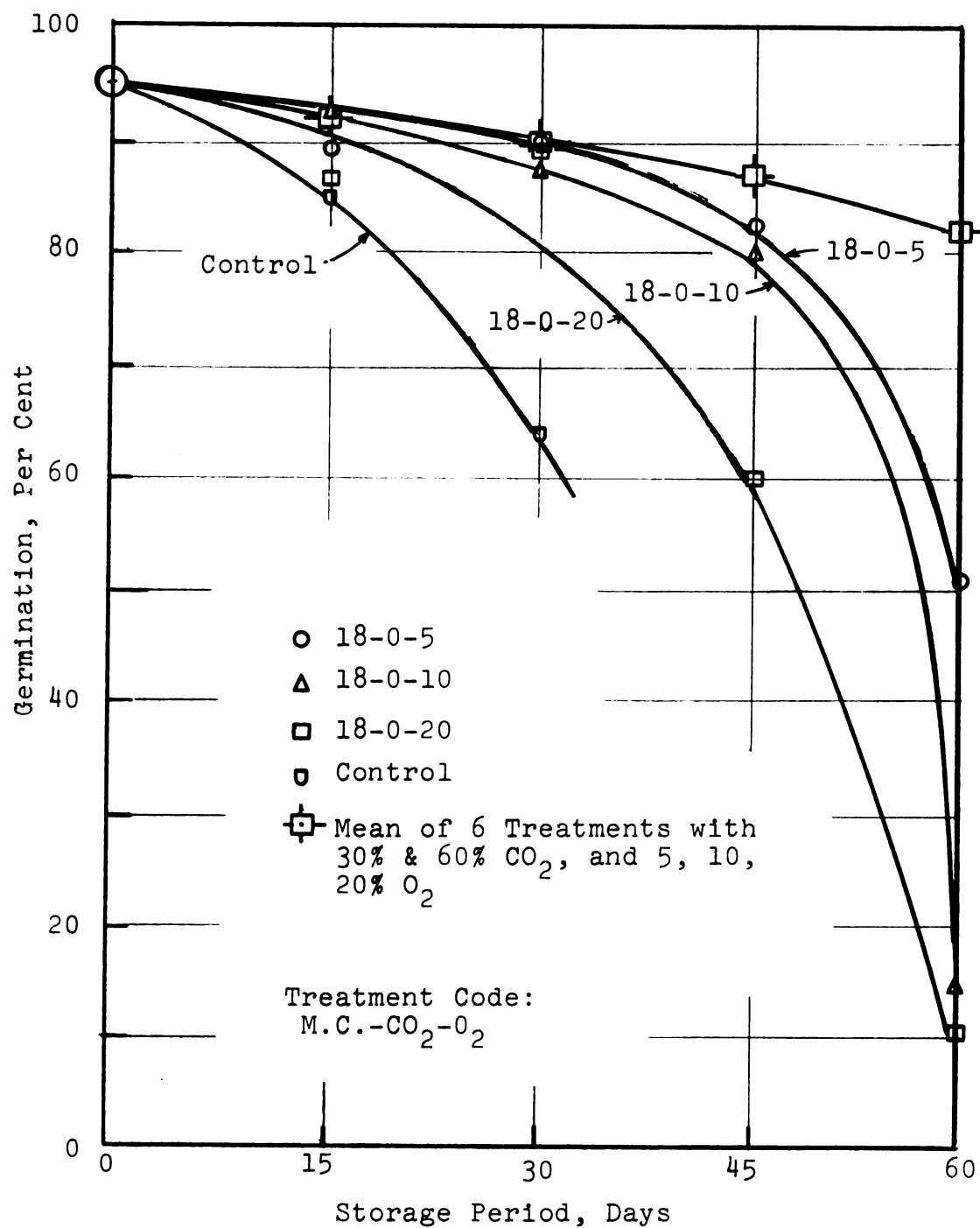


Fig. 6.9. Loss of germinating power of rice at 18% moisture content stored under different gaseous atmospheres.

Table 6.1 ANALYSIS OF VARIANCE

Measured Variable: Germination
 Treatments : 18-0-5
 18-0-10
 18-0-20

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Time	24,692.75	3	8,230.91	488.19**	4.72
Treatments	1,667.05	2	833.53	49.44**	5.61
Interaction	2,329.17	6	388.20	23.63**	3.67
Subtotal	28,668.97	11	2,606.27	154.58**	3.09
Within Groups	404.67	24	16.86		
Total	29,073.64	35			

**Highly significant.

Statistical Conclusion: The differences between the means of the several treatments at the different storage periods (time), and between means of the treatments are highly significant.

Table 6.2 ANALYSIS OF VARIANCE

Measured variable: Germination
 Treatments : 18-30-5 18-60-5
 18-30-10 18-60-10
 18-30-20 18-60-20

Sources of Variation	Sum of Squares	df	Mean Square	F Ratio	F _{0.99}
Time	1,235.84	3	411.95		4.22
Treatments	267.25	5	53.45		3.42
Interaction	532.91	15	35.53	1.88*	2.44
Subtotal	2,036.00	23	88.52		
Within Groups	906.67	48	18.89		
Total	2,942.67	71			

*There is no interaction, therefore, interaction and within group sum of squares are pooled.

Time	1,235.84	3	411.95	18.03**	4.11
Treatment	267.25	5	53.45	2.34	3.32
Residual	1,439.58	63	22.85		

**Highly significant.

Statistical Conclusion: The means of the several treatments at the different storage period (time) are highly significant, but the differences between means of treatments are not significant.

Table 6.3 ANALYSIS OF VARIANCE

Measured Variable: Germination
 Treatments : 22-0-5 22-30-5 22-60-5
 22-0-10 22-30-10 22-60-10
 22-0-20 22-30-20 22-60-20
 (for the first 15-day storage period)

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Treatments	1,537.63	8	192.20	1.93	3.71
Within Groups	1,794.67	18	99.70		
Total	3,332.30	26			

Statistical Conclusion: The differences between means of treatments are not significant.

Table 6.4 ANALYSIS OF VARIANCE

Measured Variable: Moisture Contents, before and after storage periods.

Treatment (typical example): 22-30-5-15
 22-30-5-30

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Means ¹	0.127	3	0.042	1.556	7.59
Within	0.214	8	0.027		

¹Means of moisture content before and after 15 and 30 days storage period.

Statistical Conclusion: The differences between means of treatments are not significant.

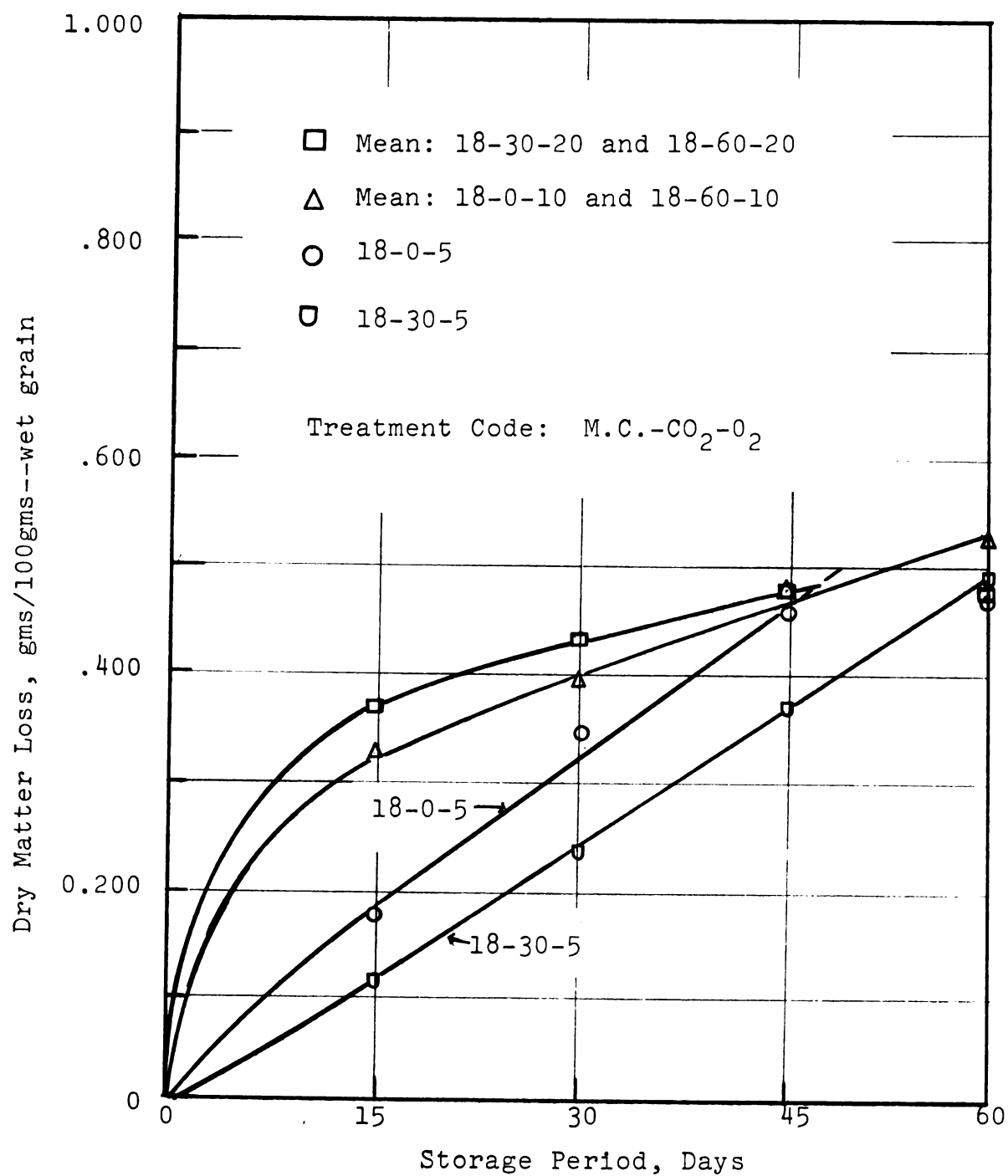


Fig. 6.10. Dry matter loss in rice at 18% moisture content in sealed storage under different gaseous atmospheres.

Table 6.5 ANALYSIS OF VARIANCE

Measured Variable: Dry Matter Loss
 Treatments : All treatments, 18% moisture content

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Time	0.889	3	0.296	148.00**	4.13
Treatments	0.809	6	0.135	67.50**	3.12
Interaction	0.223	18	0.012	6.00**	2.20
Subtotal	1.919	27	0.071	35.5**	
Within Groups	0.113	56	0.002		
Total	2.032	83			

**Highly significant.

Statistical Conclusion: The differences between means of the several treatments at the different storage periods (time) and between means of treatments are highly significant.

Table 6.6 ANALYSIS OF VARIANCE

Measured Variable: Dry Matter Loss
 Treatments : 18-0-5
 18-0-10

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Time	0.192	3	.064	64.00**	5.29
Treatment	0.013	1	.013	13.00**	8.53
Interaction	0.025	3	.008	8.00**	5.29
Subtotal	0.230	7	.033	33.00**	4.03
Within Groups	0.017	16	.001		
Total	0.247	23			

**Highly significant.

Statistical Conclusion: The differences between the means of the two treatments at the different storage periods (time) and between means of the two treatments are highly significant.

Table 6.7 ANALYSIS OF VARIANCE

Measured Variable: Dry Matter Loss
 Treatments : 18-30-5
 18-30-20

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Time	0.362	3	0.121	121**	5.29
Treatment	0.061	1	0.061	61**	8.53
Interaction	0.024	3	0.008	8**	5.29
Subtotal	0.447	7	0.064	64**	4.03
Within Groups	0.008	16	0.001		
Total	0.455	23			

**Highly significant.

Statistical Conclusion: The differences between the means of the two treatments at the different storage periods and between the two treatments are highly significant.

Table 6.8 ANALYSIS OF VARIANCE

Measured Variable: Dry Matter Loss
 Treatments : 18-60-10
 18-30-20

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Time	0.090	3	0.030	15	5.29
Treatment	0.003	1	0.003	1.5	8.53
Interaction	0.020	3	0.007	3.5*	5.29
Subtotal	0.113	7	0.016	8	4.03
Within Groups	0.034	16	0.002		
Total	0.147	23			

*No interaction. Interaction and Within Groups sum of squares are therefore pooled.

Time	0.090	3	.030	10**	5.01
Treatment	0.003	1	.003	1	8.18
Residual	.054	19	.003		

**Highly significant.

Statistical Conclusion: The differences between the means of the two treatments at the different storage periods (time) are highly significant, but differences between means of the two treatments are not significant.

Table 6.9 ANALYSIS OF VARIANCE

Measured Variable: Dry Matter Loss
 Treatments : 18-0-5
 18-30-5

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Time	.378	3	.126	157.5**	5.29
Treatment	.018	1	.018	22.5**	8.53
Interaction	.013	3	.004	5.00*	5.29
Subtotal	.409	7	.058	72.5**	4.03
Within Groups	.014	16	.0008		
Total	.423	23			

*No interaction.

Time	.378	3	.126	126**	5.01
Treatment	.018	1	.018	18**	8.18
Residual	.027	19	.001		

**Highly significant.

Statistical Conclusion: The differences of the means of the two treatments between storage periods (time) and between means of the treatments are highly significant.

Table 6.10 ANALYSIS OF VARIANCE

Measured Variable: Dry Matter Loss
 Treatments : 18-0-10
 18-60-10

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Time	0.142	3	.047	23.5**	5.29
Treatment	0.010	1	.010	5	8.53
Interaction	0.008	3	.003	1.5	5.29
Subtotal	0.160	7	.023	11.5**	4.03
Within Groups	0.027	16	.002		
Total	0.187	23			

**Highly significant.

Statistical Conclusion: The differences of the means of the two treatments between storage periods (time) are highly significant, but between the means of treatments are not significant.

Table 6.11 ANALYSIS OF VARIANCE

Measured Variable: Dry Matter Loss
 Treatment : 18-30-20
 18-60-20

Sources of Variation	Squares	df	Mean Square	F ratio	F _{0.99}
Time	0.130	3	.043	43**	5.29
Treatment	0.002	1	.002	2	8.53
Interaction	0.043	3	.014	14**	5.29
Subtotal	0.175	7	.025	25**	4.03
Within Groups	.017	16	.001		
Total	.192	23			

** Highly significant.

Statistical Conclusion: The differences of the means of the two treatments between storage periods (time) are highly significant, but between means of the treatments are not significant.

Table 6.12 ANALYSIS OF VARIANCE

Measured Variables: Dry Matter Loss
 Treatments : All treatments, 22% moisture content

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Time (Rows)	0.244	1	0.244	30.5**	7.31
Treatments (Cols.)	0.144	8	0.018	2.25	2.99
Interaction	0.013	8	0.002	0.25	2.99
Subtotal	0.401	17			
Within Groups	0.292	36	0.008		
Total	0.693	53			

** Highly significant.

Statistical Conclusion: The differences of the means of the several treatments between storage periods (time) are highly significant, but differences between means of treatments are not significant.

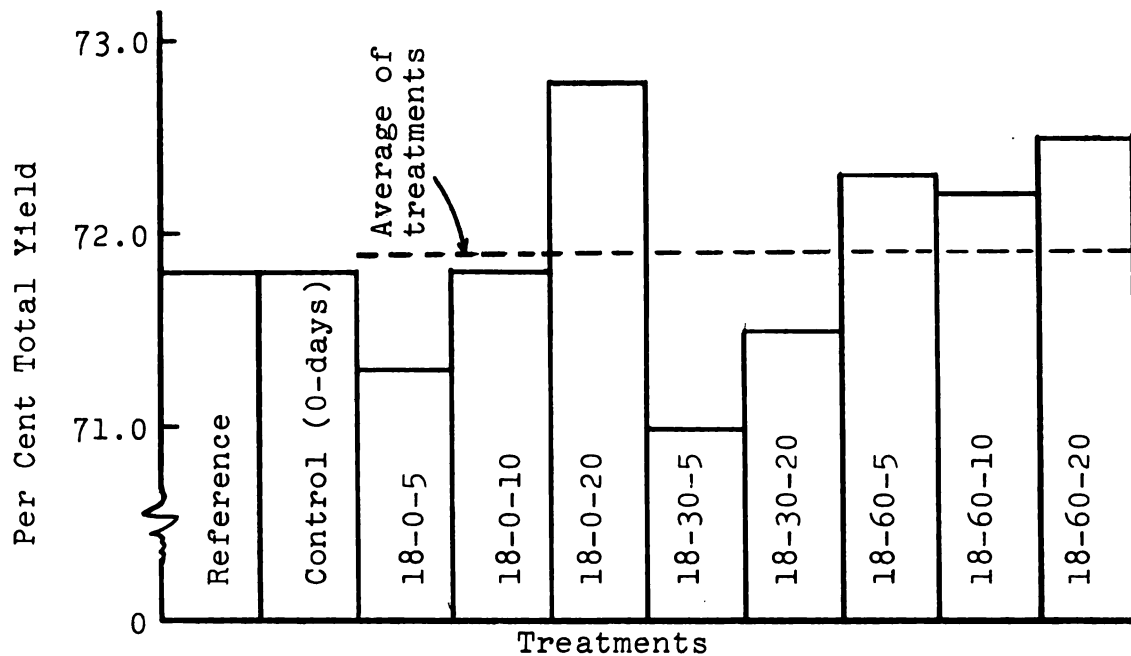


Fig. 6.11. Comparative total yields between the reference control (0-day storage), and treatments. Each treatment represents the mean of the 15, 30, 45, and 60 day storage periods (12 samples).

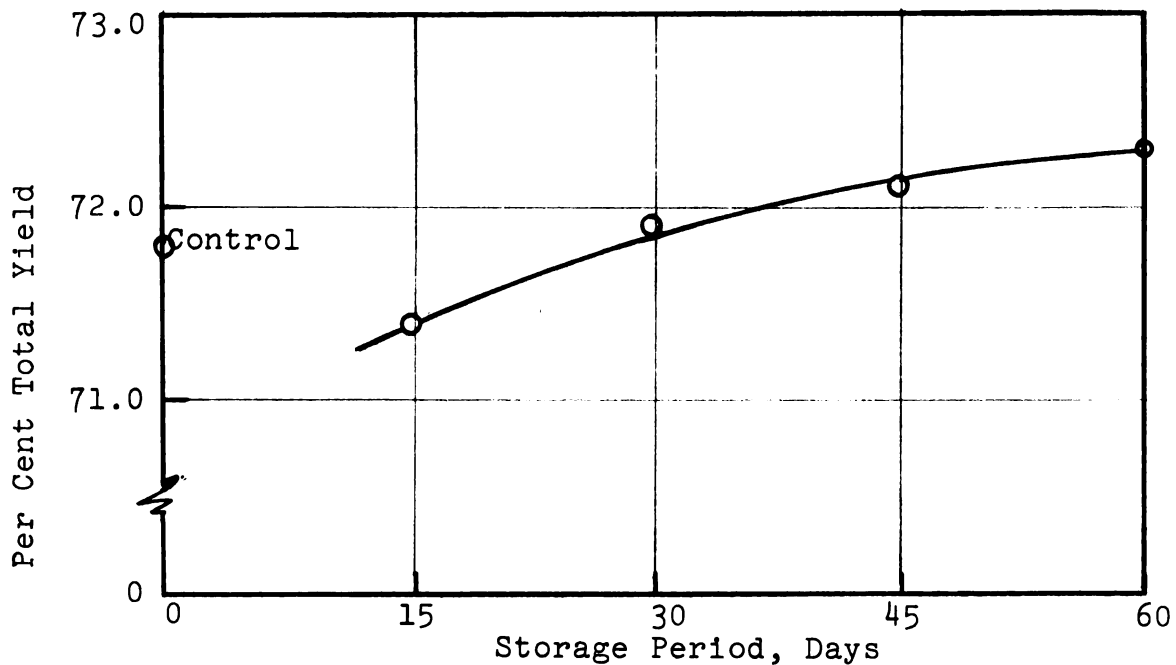


Fig. 6.12. Total yields vs. storage period. The points indicate the mean of the eight storage treatments (3 tests per treatment or 24 samples).

Table 6.13 ANALYSIS OF VARIANCE

Measured Variable: Milling Quality--Total Yield
 Treatments : All treatments, 18% moisture content

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Time	11.0	3	3.67	15.96**	4.10
Treatment	32.5	7	4.64	20.17**	2.93
Interaction	34.2	21	1.63	7.07**	2.18
Subtotal	66.7	31	2.15	9.35**	2.00
Within Group	14.9	64	0.23		
Total	81.6	95			

**Highly significant.

Statistical Conclusion: The difference between treatments are highly significant.

Table 6.14 ANALYSIS OF VARIANCE

Measured Variable: Milling Quality--Total Yield
 Treatments Compared: Reference
 Control, 0-day storage
 Over-all means of treatments, 18% m.c.

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Category Means	0.22	2	0.11	.07	4.82
Within	140.77	99	1.42		
Total	141.09	101			

Statistical Conclusion: The differences between reference, control, and over-all means of treatments are not significant.

Table 6.15 ANALYSIS OF VARIANCE

Measured Variable: Milling Quality--Total Yield
 Treatments : Reference
 Control, 0-day storage
 All treatments, 22% m.c., 15-day storage

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Category Means	7.64	10	0.764	3.82**	3.26
Within	4.43	22	0.20		
Total	12.07	32			

** Highly significant.

Statistical Conclusion: The differences between reference, control, and treatment means are highly significant.

Table 6.16 ANALYSIS OF VARIANCE

Measured Variable: Milling Quality--Total Yield
 Treatments : Reference
 Control, 0-day storage
 Over-all treatments, 22% m.c.,
 15-days storage

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Category Means	3.20	2	1.60	5.51**	5.39
Within	8.87	30	0.29		
Total	12.07	32			

**Highly significant.

Statistical Conclusion: The difference between reference control, and over-all treatment means are significant.

Table 6.17 ANALYSIS OF VARIANCE

Measured Variable: Milling Quality--Total Yield
 Treatments : Storage Period (Time)
 5, 10, 20% Oxygen levels, at
 0% CO₂, 26% m.c.

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Time	12.32	3	4.11	27.40**	4.72
Oxygen level	0.68	2	0.34	2.26	5.61
Interaction	7.47	6	1.24	8.26**	3.67
Subtotal	20.47	11	1.86	12.40**	3.09
Within Groups	3.66	24	0.15		
Total	24.13	35			

**Highly significant.

Statistical Conclusion: The differences in means of the three oxygen levels for the different storage periods (time) are highly significant, but the difference in means between the three oxygen levels are not significant.

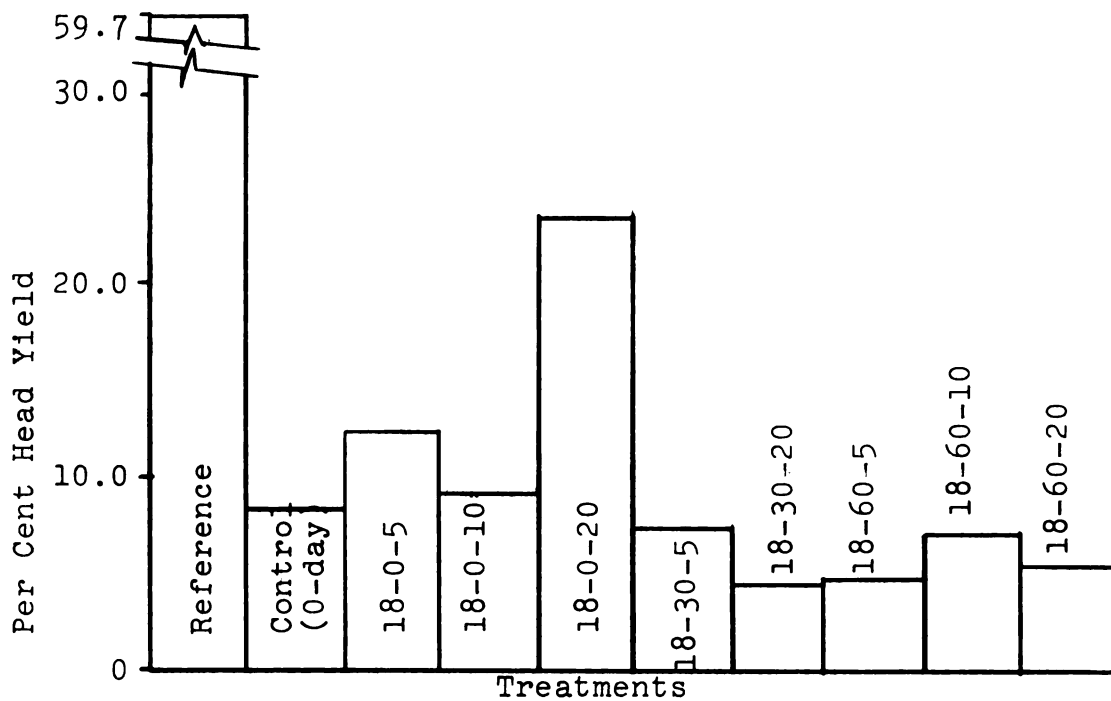


Fig. 6.13. Comparative head yields between the reference, control (0-day storage), and treatments. Each treatment represents the mean of the 15, 30, 45, and 60 day storage period (12 samples).

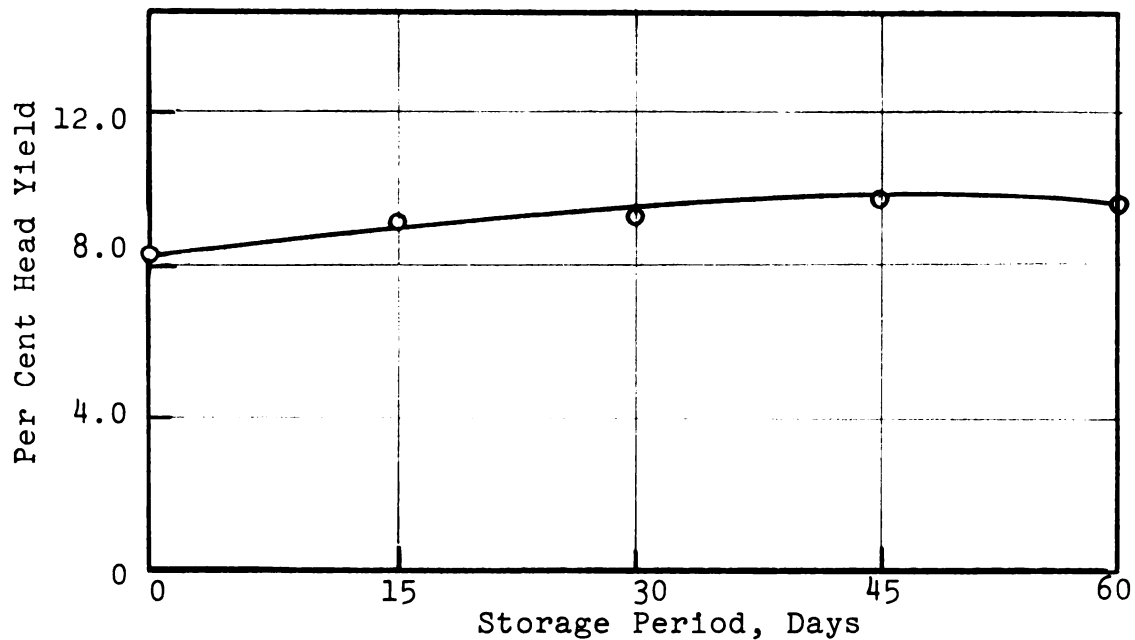


Fig. 6.14. Head yields vs. storage period. The points indicate the mean of the eight storage treatment (24 samples).

Table 6.18 ANALYSIS OF VARIANCE

Measured Variable: Milling Quality--Head Yield
 Treatments : Storage Period (Time)
 All Treatments, 18% m.c.

Source of Variations	Sum of Squares	df	Mean Square	F ratio	F _{0.99}
Time	5.03	3	1.68	9.18**	4.12
Treatment	2,328.09	7	332.58	1,817.37**	2.94
Interaction	1,084.42	21	51.64	282.18**	2.18
Subtotal	3,417.54	31	110.24	602.40**	2.00
Within Group	11.71	64	0.183		
Total	3,429.25	95			

**Highly significant.

Statistical Conclusion: Differences between means are significant.

Table 6.19 ANALYSIS OF VARIANCE

Measured Variable: Milling Quality--Head Yield
 Treatments : Control (0-day storage)
 All treatments, 22% m.c. 15 days storage

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Category Means	23.08	9	2.56	1.78	3.45
Within	28.73	20	1.44		
Total	51.81	29			

Statistical Conclusion: The differences between treatment means and control are not significant.

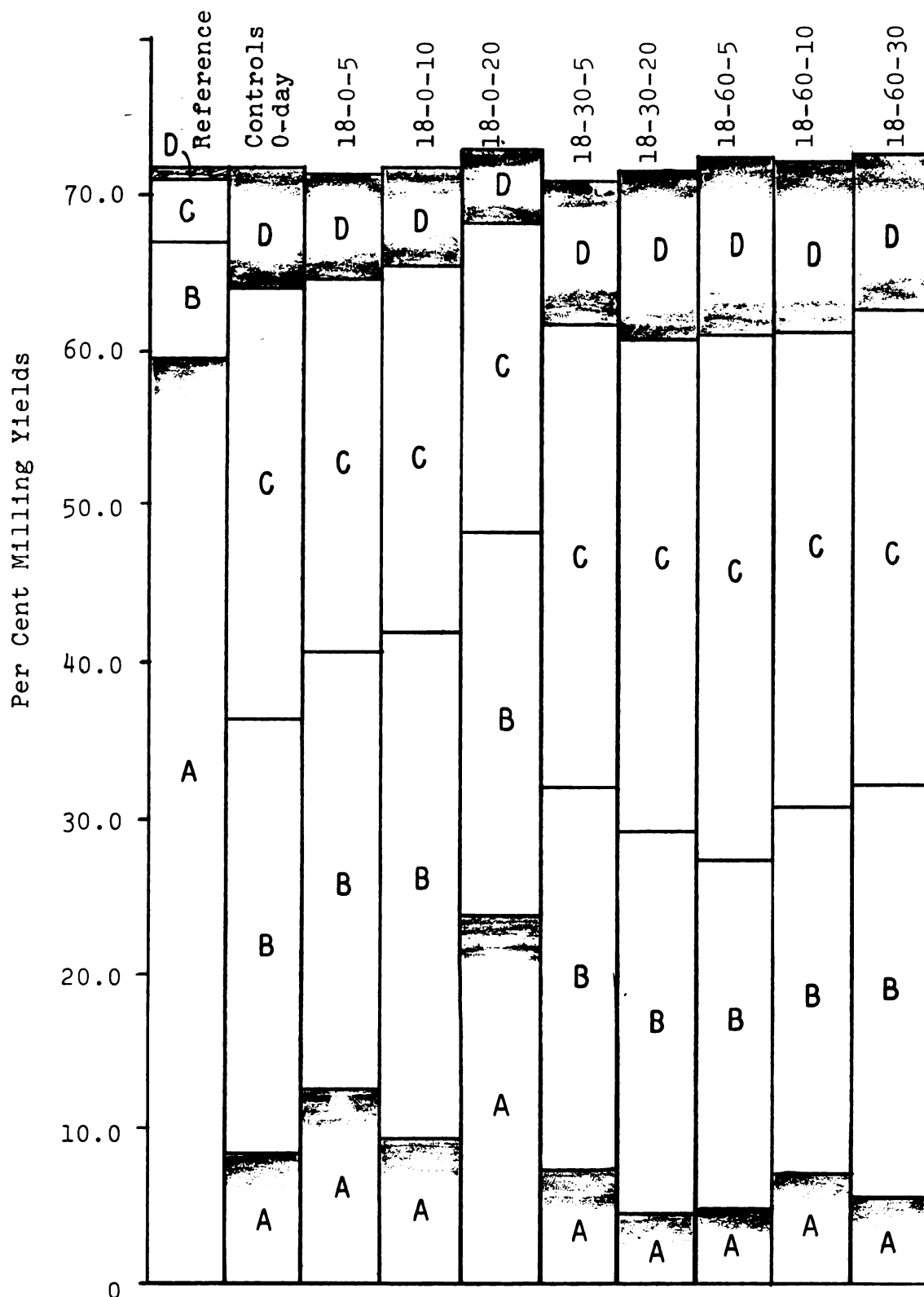


Fig. 6.15. Comparative distribution of the grain sizes after milling showing (A) head rice, (B) second head (1/2 to 3/4 grain), (C) screenings (1/4 to 1/2 grain), (D) brewers (1/4 or smaller) rice (mean of 12 samples).

Table 6.20 ANALYSIS OF VARIANCE

Measured Variable: Milling Quality--Second Head
 Treatments : Storage Period (Time)
 All Treatments, 18% m.c.

Sources of Variation	Sum of Squares	df	Mean Square	F _{ratio}	F _{0.99}
Time	57.47	3	19.16		
Treatments	841.37	7	120.20		
Interaction	416.50	21	19.83	2.10*	2.18
Subtotal	1,315.34	31	42.43		
Within Group	603.73	64	9.43		
Total	1,919.07	95			

*No Interaction, therefore, Interaction and Within Group Sum of Squares are pooled.

Time	57.47	3	19.16	1.59	4.00
Treatment	841.37	7	120.20	10.01**	3.00
Residual	1,020.23	85	12.0		
Total	1,919.07	95			

**Highly significant.

Statistical Conclusion: The differences between the means of several treatments for the different storage periods (time) are not significant, but the differences in the means between treatments are highly significant.

7. SUMMARY AND CONCLUSIONS

7.1 Summary

The development of a method of storing high moisture rough rice has been identified as a key to the problems of bulk storage in damp climates. In addition, such a method has other advantages as allowing longer drying time and higher drying capacity. A sealed storage system under reduced oxygen atmospheres offers such a possibility.

This experiment was designed to investigate the feasibility of a sealed storage system for rough rice at moisture contents above normal. The influence of various initial concentrations of the main components of air on the respiration rates, dry matter loss, viability, and milling quality for different lengths of storage periods.

Oxygen, carbon dioxide, and nitrogen were blended at different proportions. Sealed storage systems were simulated on a laboratory scale with gallon glass jars. Provisions for flushing the original atmospheres with the desired gases and for sampling the storage atmosphere for analysis at the end of the storage period were made.

7.2 Conclusions

The conclusions drawn from this experiment are based on the data collected from measurements on 2.200 Kg. samples

of rough rice (variety Nato, grown in Louisiana) subjected to the various storage treatments. The numerical magnitude of the results may differ with other varieties grown under different climatic environments, but there is no reason to assume loss of generality in the application of results to other varieties from different climates.

The following conclusions are made:

1. The oxygen levels in all treatments with 20% initial concentrations were completely depleted within 15 days with the 18%, 22%, and 26% moisture content levels. Respiration, therefore, within 15 days of sealing is anaerobic.

2. The increase in carbon dioxide concentrations served as a good index for comparative study of the respiration rates for the various storage treatments. The initial presence of oxygen in the interstitial grain atmosphere induces significantly higher total respiration rates compared to atmospheres with reduced oxygen concentrations. Repeated exposures, therefore, of the stored grain to a source of oxygen such as air would cause higher total respiration rates and consequently would cause heating in the grain mass. The rate of anaerobic respiration, however, is not influenced by the initial oxygen level.

3. The accumulation of carbon dioxide in the interstitial atmosphere of the grain significantly reduces total respiration rates. Treatments wherein the carbon dioxide

levels were artificially increased had much lower net carbon dioxide evolved.

4. As is generally known, grain with higher moisture contents have higher respiration rates. Using identical gas treatments (ordinary air: 0% carbon dioxide and 20% oxygen) with 18% moisture grain, the carbon dioxide concentrations rose to 54% in 30 days; with 22% moisture grain, carbon dioxide concentration rose to 73% in 30 days; and with 26% moisture grain, a high 90% was reached.

5. Germination is a very sensitive index of the quality of the grain. It is safe to conclude that rice grain that germinates, however low the viability, if intended for milling, is good grain. This conclusion conforms to the theory of Bailey (1920) that the seat of respiration is in the germ of the grain where there is greater abundance of the reducing enzymes. Treatments whose germinating power dropped to 10% in 60 days showed no loss of milling quality and, in fact, had better total and head yields compared to the others.

6. The germination tests confirmed that the higher respiration rates were higher where initial oxygen concentration was high. This was observed in treatments with 0% initial carbon dioxide, and 18% moisture content.

7. The germination tests also confirmed the beneficial influence of high carbon dioxide concentrations in the grain interstitial atmosphere. Treatments with 18% moisture content

with initial carbon dioxide concentrations artificially increased to 30% and 60%, maintained an 82% viability after 60 days in storage.

8. The germination test with the 22% moisture grain showed high rates of metabolism. The inhibiting influence on the respiration showed by the reduced oxygen or increased carbon dioxide atmospheres at the 18% moisture level, was no longer apparent at the 22% moisture level. There was no significant difference between treatments. Germination dropped to 28% in 15 days and practically zero within 30 days. With the 26% moisture grain, germination was completely lost in all treatments within 15 days.

9. The presence of oxygen in the grain atmosphere significantly affects dry matter loss. Treatments at the 18% moisture content level with higher initial oxygen concentration had significantly higher dry matter loss. The over-all average dry matter loss for all treatments with 18% moisture content is in the order of 0.500 gms. per 100 gms. of the wet grain, after 60 days in sealed storage.

10. The influence of carbon dioxide on the dry matter loss was not conclusive. With the 18% moisture content, only in the treatments with 5% oxygen, did a higher carbon dioxide concentration show a significantly lower dry matter loss. The other treatments at the higher oxygen levels did not show significant difference in dry matter loss between the high and low carbon dioxide concentrations. With the

22% moisture grain, evaporation of moisture from the wet grain surface to the dry laboratory atmosphere caused high variance between replications. Differences between treatments were not significant.

11. The milling quality of the grain was not adversely affected in any way in sealed storage for 60 days for all treatments with 18% moisture content. With the 22% moisture grain, a slight musky odor remained even after milling. With the few treatments tried at 26% moisture, the grain showed a high degree of heat damage and developed a severely objectionable odor.

12. The over-all mean of 96 samples for the total milling yield with the 18% moisture grain was maintained at 71.8%. The reference sample had a total yield of 71.8%. Nato varieties have normal total yields of 70 to 74%. Significant variations in the order of 1% between gas treatments of 24 samples were measured with a total yield highest in the treatment sealed with ordinary air. The same trend was observed with the 22% moisture grain, where an over-all mean of 71.5% total yield was obtained.

13. A significant increase in total yield is indicated with storage time. An increase of about 1% from the mean of 24 samples was measured between the 15-day and 60-day storage periods, with the 18% moisture grain. A 1% increase in total yield is enough to replace the rice shortage in the Philippines which has an annual total production of about 1.5 million metric tons.

14. The head yields with the 18% moisture grain compared to a control sample which was remoistened, tempered, and redried but not subjected to any storage treatment shows no adverse effect by the sealed storage. Expressing the ratio of the treatment head yield to the control head yield, the over-all mean of 96 samples has a milling yield index of 1.15. In the treatment sealed with ordinary air, the mean of the 12 samples shows a milling head yield index of 2.90.

15. A slight significant increase in head yield is again indicated with storage time up to about 45 days; with the treatments at 18% moisture content.

16. The difference between the total yield and the head yield represents the broken grains classified into three categories of second head, screenings, and brewer's rice. In general, the treatments with higher total and head yield had lower brewer's rice. The loss in yields are primarily due to the finely broken grains carried away in the milling process.

17. Sealed storage can be adopted for rice intended for milling and human consumption. An upper limit of 18% moisture content may be safely stored in a sealed storage system for periods beyond the 60 days investigated in this experiment. At 18% moisture, grain will spoil within 15 days in conventional bulk storage. While the investigation shows that artificially reducing the oxygen and increasing the carbon dioxide concentrations are generally beneficial

to the respiration rates, viability, and dry matter loss, and while it has significant influence on the milling quality, it is small and not conclusively adverse; and since sealing with ordinary air has no greatly adverse effects, on the contrary, a beneficial effect on the milling quality was observed, the sealed storage with ordinary air may be more economically developed.

Drying of rice is necessary to obtain good milling recoveries, but maintaining the grain in a dried state in a bulk system in damp climates is difficult. It is, therefore, proposed that an operating schedule in a grain drying and storage center be studied whereby grain harvested above 18% may be passed through a dryer to remove some of the moisture. This initial pass could well drop the moisture within 18%, after which the grain may be stored in a sealed storage system. Further drying of the grain for the mill could then be done on a longer schedule after the rush of the harvest season.

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