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On the Effect of Air-Tight and Carbon Dioxide upon the Storage of Rice.

By

Mantarō Kondō and Tamotsu Okamura.

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Introduction.

In Japan it is a long standing custom to store the hulled rice (*Genmai*) in straw-bags. Since hulled rice in straw-bags is much damaged by insects, vermin, mould and mice, a study of storing method is important.

Since 1915 the writers have studied the storage of rice and particularly the change of its physical properties during this period. The results of the investigations have been reported briefly already in 1926[1]. As conclusion it is reported that for the storage of hulled rice it is very important to dry the grains at first, to protect it from moisture during the time of storage, to cool the grains and granary air during the summer and keep the insects in check. Air-tight vessels or ware-houses afford a good condition for storage.

Since 1925 the writers have made other experiments. They wanted to study the effect of air-tight apartments and also the effect of carbon dioxide upon the storage of rice. The materials used are the hulled rice of "Shinriki" and "Omachi", which were harvested in the autumn of 1924. The experiments continued from May 1925 up to the present. In the present paper the writers want to describe the results of these investigations briefly.

I. Materials and Experimental Methods.

The materials of investigation were the hulled rice of "Shinriki" and "Omachi" of 1924. They were dried very thoroughly. In the beginning of the experiment, the moisture of "Shinriki" was 11.8%, and that of "Omachi" 11.3%. The materials were divided into three and stored by the three following methods.

A. The hulled rice was stored in the large zinc vessel with carbon dioxide. The carbon dioxide was prepared in a Kipp's apparatus and dried and purified in the usual way. The quantity of rice used was exactly 2 *To**. 200 weevils of *Calandra oryzae* were placed into the vessel. (Carbon dioxide storage.)

B. In the same zinc vessel as A 2 *To* of the hulled rice were stored and the vessel was closed tightly. (Air-tight storage.)

C. In the common straw-bags (*Tawara*) 2 *To* of the hulled rice were stored. (Straw-bag storage.)

These vessels and straw-bags of rice were placed in the same granary of the Ōhara-Institute (Plate. I).

Before the storage, the writers investigated the weight and volume of whole rice, weight of 1000 grains, moisture, volume weight, and hardness of rice, material lost by polishing rice and other qualities of rice.

In November 1925 the writers opened the straw-bags and zinc vessels, investigated weight, volume and several qualities of rice grains and soon closed the vessels and bags as before. It is the first time of testing the rice. In November—December 1926 they tested the stored rice the second time, and in September—October 1927 the third time. This experiment has continued up to the present over a period of 4 years and will continue further, but the storage of rice in straw-bags was finished in September—October 1927, after 3 years, because the rice in straw-bags was much damaged by weevils.

II. Results of the Storage of Rice.

1. Weight and volume of the stored rice.

Since the change of weight and volume of the rice during the time of storage is the most important problem in rice storage, in the first place the

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*Ca. 2 *To* = 1 Bushel.

writers have investigated the question from 1925 until 1927. Rice stored in straw-bags, is much damaged by weevils. In the measurement of weight and volume, the insects, their excrement, damaged grains etc have not been excluded.

The results are as follows:—

Table 1.

Variation of weight of the stored rice.

Material	Method of storage	Initial weight in May 1925	November 1925	November 1926	September 1927	Difference between 1925 and 1927	Remarks.
		Kan	Kan	Kan	Kan	Kan	
Shinriki	CO_2 storage	8.260	8.268	8.249	8.282	+0.022	without damage of insects.
	Air-tight storage	8.260	8.268	8.239	8.261	+0.001	
	Straw-bag storage	8.260	8.734	8.269	7.281	−0.979	much damaged by insects.
Omachi	CO_2 storage	8.360	8.344	8.340	8.262	−0.098	without damage of insects.
	Air-tight storage	8.360	8.348	8.340	8.318	−0.042	
	Straw-bag storage	8.360	8.812	8.056	7.047	−1.313	much damaged by insects.

Remarks. 1 *Kan* = 3.75 Kg.

If you put the initial weights of the stored rice by the three methods as 100 and calculate their weights during the time of storage, you can get the indicies of weight in Table 2.

Table 2.

Variation of indicies of weight of the stored rice.

Material	Method of storage	Initial weight in May 1925	November 1925	November 1926	September 1927	Difference between 1925 and 1927
Shinriki	CO_2 storage	100	100.1	99.9	100.3	+0.3
	Air-tight storage	100	100.1	99.8	100.0	0
	Straw-bag storage	100	105.7	100.1	88.2	−11.8
Omachi	CO_2 storage	100	99.8	99.8	98.8	−1.2
	Air-tight storage	100	99.9	99.8	99.5	−0.5
	Strawb-ag storage	100	105.4	96.4	84.3	−15.7

As Table 1 and 2 show, by the carbon dioxide storage the weight of stored rice is almost constant. Small change of weight may be caused only by the experimental error. By the air-tight storage it is just like the carbon dioxide storage. By these two methods there is no quantitative loss of rice during the time of storage.

By the straw-bag storage it is quite different from the above mentioned results. In the first year of storage, the weight of rice increased much, because the good dried rice absorbed the moisture from the air to a great extent. But in the second year the weight of rice decreased much on the contrary, because the moisture of rice decreased by the effect of aging and the grains damaged by weevils. In the third year the decrease of weight was much greater than before, because the grains were damaged much more. By the straw-bag storage the loss of rice is therefore very great.

The variation of volume of rice during the time of storage is given in Table 3 and 4.

Table 3.

Variation of volume of the stored rice.

Material	Method of storage	Initial volume in May 1925	November 1925	November 1926	September 1927	Difference between 1925 and 1927	Remarks.
		To	To	To	To	To	
Shinriki	CO_2 storage	2.000	2.000	2.053	2.053	+0.053	without damage of insects.
	Air-tight storage	2.000	2.000	2.046	2.049	+0.049	
	Straw-bag storage	2.000	2.187	2.184	2.184	+0.184	much damaged by insects
Omachi	CO_2 storage	2.000	2.000	2.046	2.041	+0.041	without damage of insects.
	Air-tight storage	2.000	1.997	2.043	2.047	+0.047	
	Straw-bag storage	2.000	2.173	2.142	2.120	+0.120	much damaged by insects

Remark. 1 *To* = 0.497 bushel.

If you put the initial volume of the stored rice in May 1925 as 100 and calculate the volume indicies during the time of storage, you can get the results in Table 4.

Table 4.

Variation of indicies of volume of stored rice

Material	Method of storage	Initial volume in May 1925	November 1925	November 1926	September 1927	Difference between 1925 and 1927
Shinriki	CO_2 storage	100	100	102.7	102.7	+2.7
	Air-tight storage	100	100	102.3	102.5	+2.5
	Straw-bag storage	100	109.4	109.2	109.2	+9.2
Omachi	CO_2 storage	100	100	102.3	102.1	+2.1
	Air-tight storage	100	99.9	102.2	102.4	+2.4
	Straw-bag storage	100	108.7	107.1	106.0	+6.0

The volume of rice may be influenced by different factors. A rough seed coat, broken grains, absorption of moisture etc cause the increase of volume of rice. Smooth seed coat causes on the contrary the decrease of its volume. The rice stored in the air-tight or carbon dioxide vessels is coated very smooth, and suffered no damage. The volume of stored rice should always be constant, but in fact it increased slightly as Table 3 and 4 show, while the rice absorbed the moisture rapidly, when the vessels were opened for testing rice.

By the straw-bag storage method the volume of rice always increased much, in spite of the fact that the rice was damaged by weevils and its weight decreased much as already described. The absorption of moisture, roughness of surface of grains, mixture of broken grains, excrement of insects, powder of rice etc caused the incsease of volume of rice stored in straw-bags. It is very interesting to see that the quantitative loss of rice was very great, but its volume on the contrary increased very much. The relationship between the weight and volume of rice is quite opposite. In the quantitative investigation of grains "Weight" must be always used instead of "Volume".

2. Moisture of rice.

From 1925 to 1927 the variation of the moisture of rice was studied during the time of storage, with the following results.

Table 5.

Variation of moisture of the rice during the time of storage.

Material	Method of storage	Initial moisture in May 1925	November 1925	November 1926	September 1927	Difference between 1925 and 1927
		%	%	%	%	%
Shinriki	CO^2 storage	11.80	12.10	12.96	11.60	−0.20
	Air-tight storage	11.80	12.00	12.90	11.81	+0.01
	Straw-bag stoarge	11.80	14.85	14.98	13.20	+1.40
Omachi	CO_2 storage	11.27	10.90	12.18	11.20	−0.07
	Air-tight storage	11.27	11.30	12.30	11.20	−0.07
	Straw-bag storage	11.27	14.10	14.94	12.73	+1.46

The moisture of rice of air-tight or carbon dioxide storage should be always invariable during the time of storage. According to Table 5, however, the moisture of rice in the zinc vessels increased gradually during the first and second year, because the rice absorbed the moisture rapidly, when the vessels were opened to test the rice. In the third year on the contrary the moisture of rice decreased owing to the decrease of water holding ability of grains. As Table 5 shows, there is no difference of moisture between the carbon dioxide storage and the air-tight storage.

The moisture of rice in straw-bags increased greatly in the first and second year, because it is affected in a great degree by the atmospheric humidity. It is quite different from the storage in zinc vessels. In the third year the moisture of rice decreased again, owing to the aging. About the variation in the moisture of rice stored in straw-bags the writers studied particularly and reported already[8].

In comparison it should be said that the rice in straw-bags is affected by the atmospheric humidity in a great degree and the thoroughly dried grains absorb moisture freely from the atmosphere. The rice in the zinc vessels is protected from moisture while in storage and always remains dry.

3. Volume weight of rice.

The writers studied the variation of volume weight of rice during the time of storage with the following results.

Table 6.

Variation of the volume weight of hulled rice.
Weight of a hectoliter.

Material	Method of storage	Initial volume weight in May 1925	November 1925	November 1926	September 1927	Difference between 1925 and 1927	Remarks.
		Kg	Kg	Kg	Kg	Kg	
Shinriki	CO_2 storage	85.89	85.95	86.85	87.62	+1.73	increase gradually
	Air-tight storage	85.89	86.01	86.45	87.39	+1.50	
	Straw-bag storage	85.89	83.09	78.66	73.34	−12.55	decrease gradually
Omachi	CO_2 storage	86.57	86.41	87.48	88.36	+1.79	increase gradually
	Air-tight storage	86.57	86.54	87.37	88.55	+1.98	
	Straw-bag storage	86.57	84.00	79.06	73.78	−12.79	decrease gradually

According to Table 6 the volume weight of hulled rice stored in zinc vessels, air-tight or with carbon dioxide, always increased gradually. It is a sign of the good quality of rice grains. There is no difference of volume weight between the carbon dioxide storage and the air-tight storage.

By the straw-bag storage, on the contrary, the volume weight decreased in a great degree. This indicates the deterioration of quality of grains during the time of storage. The decrease of the volume weight of grains is caused mainly by the absorption of moisture from the atmosphere and also by the heavy damage of insects.

The variation in the volume weight of rice shows that the hulled rice in an air-tight vessel or in a carbon dioxide vessel, is kept always in a very good condition, but the rice in straw-bags deteriorates in its quality in a great degree.

4. Hardness of rice.

The hardness of the grains is one of the important properties of rice. When the hardness of the grains is increased the keeping quality is improved and the material lost by polishing is decreased. The writers investigated the variation of hardness of rice during the time of storage. The hardness was tested by KITAO's instrument. There are two kinds of hardness. When a grain is broken under pressure the pressure weight is taken as "hardness against breaking" but when a grain is crushed under pressure, the pressure weight is taken as "hardness against crushing". The hardness is generally denoted by *Kg*. The following results were obtained.

Table 7.

Variation of Hardness of rice grains during the time of storage.

A. Hardness against breaking.

Material	Method of storage	Initial hardness in May 1925	November 1925	November 1926	September 1927	Difference between 1925 and 1927	Remarks.
		Kg	Kg	Kg	Kg	Kg	
Shinriki	CO_2 storage	8.832	8.370	10.328	10.461	+1.629	increased greatly
	Air-tight storage	8.832	7.883	10.012	9.551	+0.719	
	Straw-bag storage	8.832	6.513	8.215	8.220	−0.612	decreased
Omachi	CO_2 storage	8.523	7.898	10.709	10.795	+2.272	increased greatly
	Air-tight storage	8.523	7.409	9.629	9.943	+1.420	
	Straw-bag storage	8.523	6.488	7.009	7.536	−0.987	decreased

B. Hardness against crushing.

Material	Method of storage	Initial hardness in May 1925	November 1925	November 1926	September 1927	Difference between 1925 and 1927	Remarks.
Shinriki	CO_2 storage	9.029	9.511	10.946	10.960	+1.931	increased greatly
	Air-tight storage	9.029	9.297	10.804	10.987	+1.958	
	Straw-bag storage	9.029	8.137	8.743	8.936	−0.093	decreased slightly
Omachi	CO_2 storage	9.718	10.253	11.423	11.537	+1.819	increased greatly
	Air-tight storage	9.718	9.732	10.344	11.172	+1.454	
	Straw-bag storage	9.718	7.830	8.272	8.817	−0.901	decreased

As Table 7, A shows, the hardness against breaking of rice grains, which are stored in the air-tight vessels or in the carbon dioxide vessels, decreased in the first year slightly, but in the second and third year, on the contrary increased gradually.

In regard to the hardness of rice against crushing, it always increased. Generally the hardness of rice increases during the time of storage in zinc vessels and this fact shows that the rice was kept in a good condition. In comparison it seems that the hardness of rice of the carbon dioxide storage is somewhat greater than that of the air-tight storage.

The hardness of the rice in the straw-bags decreased in the first year, but in the second and third year it increased slightly again, however never increasing to the initial hardness. In the previous paper KONDO[3] reported that the hardness of the hulled rice stored in straw-bags decreased during the first two or three years, but after several years it increased again.

In comparison the hardness of rice in straw-bags is smaller than that of rice in zinc vessels to a remarkable degree. The cause of the difference is as following. The hardness of rice is affected by the moisture and also by the aging in a great degree. The rice in the zinc vessels is protected from moisture perfectly, but the rice in the straw-bags is affected by the atmospheric humidity during the time of storage.

5. Material lost by polishing rice.

The writers investigated the material lost by polishing the stored rice with the following results.

Table 8.

Material lost by polishing of hulled rice.

% in weight.

Material	Method of storage	In the beginning of the storage May 1925	November 1925	November 1926	September 1927	Difference between 1925 and 1927	Remarks.
		%	%	%	%	%	
Shinriki	CO_2 storage	7.73	6.17	6.18	6.15	−1.58	decreased
	Air-tight storage	7.73	6.44	6.39	6.18	−1.55	
	Straw-bag storage	7.73	9.87	10.42	13.93	+6.20	increased greatly
Omachi	CO_2 storage	6.84	6.22	6.07	6.08	−0.76	decreased
	Air-tight storage	6.84	6.47	6.68	6.10	−0.74	
	Straw-bag storage	6.84	9.42	10.22	13.27	+6.43	increased greatly

The above table shows that the material lost by polishing the rice in zinc vessels, air-tight or with carbon dioxide, decreased with the length of time of storage, because the grains were perfectly protected against insects, mould and moisture. By the rice in straw-bags, on the contrary, it increased in a great degree, because the grains are damaged by insects heavily and affected by the atmospheric humidity during storage. Besides the writers observed that the polishing of the rice in the zinc vessels needed much more time than that of the rice in the straw-bags, because by the former the grains got drier and harder than the latter.

In comparison of the carbon dioxide storage with the air-tight storage, it was observed that by the carbon dioxide storage the material lost by polishing is only a little smaller than that by the air-tight storage. This fact coincides with the relationship in the hardness of grains, as stated already.

The material lost by polishing is one of the important problems of storage and from that point of view, the storage of rice in the air-tight or more in the carbon dioxide vessels is much more profitable than the storage in straw-bags, which is most common in Japan.

6. "Kamabue"

When the white rice is boiled in a kettle its volume increases greatly. The percentage of increase in volume of boiled rice to the original volume of white rice, $\left(\frac{\text{Volume of boiled rice} - \text{volume of white rice}}{\text{Volume of white rice}} \times 100\%\right)$ is called "*Kamabue*". In the previous paper KONDO[5] reported that "*Kamabue*" of rice increases regularly with the length of time of storage in the straw-bags. In this study the writers investigated the relationship between "*Kamabue*" and the methods of storage and got the following results.

Table 9.

"Kamabue" of the stored rice.

Material	Method of storage	New[1] rice	After one year	After two years	After three years
		%	%	%	%
Shinriki	CO_2 storage	105.5	108.6	118.6	125.0
	Air-tight storage	105.5	110.2	118.6	123.1
	Straw-bag storage	105.5	114.1	118.0	109.4
Omachi	CO_2 storage	104.0	109.5	121.6	123.8
	Air-tight storage	104.0	112.5	117.3	123.8
	Straw-bag storage	104.0	114.4	117.0	110.8

Remark. 1) Newly harvested rice in 1927.

According to Table 9 "*Kamabue*" of rice stored in the air-tight vessels or in the carbon dioxide vessels increased regularly with the length of time of storage. By the rice in the straw-bags it increased in the first and second years, but in the third year it decreased a little owing to the damage by insects.

Generally "*Kamabue*" of rice increases gradually while in storage. There is no distinguishable difference of "*Kamabue*" between the rice in the zinc vessels and straw-bags, but after three years storage there occurred a great difference, by the rice stored in the air-tight or in the carbon dioxide vessels it is greater than that of the rice in straw-bags.

7. Qualities of boiled rice.

The writers investigated the taste, smell, stickiness and colour of the boiled rice (*Meshi*). The results are shown in a tabular form on the next page. (Table 10, P. 11)

As Table 10 shows, the taste of the boiled rice was somewhat undesirable, when the rice was stored only one year in a straw-bag; after two years the taste, smell, colour etc of the boiled rice became very bad and the rice could scarcely be eaten; after three years it became very bad and could not be eaten at all.

The rice stored in the air-tight or in the carbon dioxide vessels always kept its good qualities. After three years of storage the qualities like taste, smell, colour etc of the boiled rice were however very good. In comparison the rice stored in the carbon dioxide had better qualities than the rice in the air-tight vessels.

8. Viscosity of rice paste.

To determine the relationship between the viscosity of rice paste and the effects of the three methods of storage, the writers investigated this quality of the stored rice in 1926 and 1927. To compare with the stored rice, they investigated the viscosity of new rice.

The paste had the density of 5% (water 100 g : rice powder 5 g) and the temperature of 40°C. It was tested by STORMER's viscosimeter*, which was made by TANAKA & Co. Taking the viscosity of water of 40°C as 1 (standard) the viscosity of the paste was determined. The results are shown in Table 11.

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*STORMER's viscosimeter is so constructed to rotate a cylinder in the liquid driven by a constant weight. The time required for the cylinder to make a special number of revolution in distilled water and in the substance, in this case paste, under the examination, forms the basis of comparison.

Table 10.

Qualities of boiled rice.

Material	Method of storage	November 1925			November 1926			October 1927		
		taste	smell	stickiness	taste	smell	colour	taste	smell	colour
Shinriki	CO_2 storage	good	good	sticky	good	fairly good	white	fairly good	good	white
	Air-tight storage	good	good	sticky	good	fairly good	white	fairly good	fairly good	white
	Straw-bag storage	fairly bad	moderate	without stickiness	bad	fairly bad	grayish white	not eatable	bad	grayish brown
Omachi	CO_2 storage	good	good	sticky	moderate	fairly good	white	good	good	white
	Air-tight storage	good	good	sticky	good	moderate	white	good	fairly good	white
	Straw-bag storage	fairly bad	moderate	without stickiness	bad	moderate	grayish white	not eatable	bad	grayish brown

Remark. The rice was stored in May 1925.

Formerly KONDO[3] reported that the viscosity of the rice paste decreased suddenly during summer, and especially after the lapse of three summers the viscosity of the paste decreased in a great degree, when it was stored in straw-bags. According to Table 11 the viscosity of the rice paste decreased gradually during the time of storage, particularly in the rice in the straw-bags it decreased in a great degree, as above stated, but in the rice in carbon dioxide vessels on the contrary relatively in a lesser degree.

Table 11.

Viscosity of rice paste.

Material	Method of storage	New[1] rice	After two years, 1926	After three years, 1927	Remark
Shinriki	CO_2 storage	1.81	1.78	1.74	viscosity of water of 40°C = 1.
	Air-tight storage	1.81	1.75	1.69	
	Straw-bag storage	1.81	1.73	1.59	
Omachi	CO_2 storage	1.93	1.92	1.76	
	Air-tight storage	1.93	1.90	1.69	
	Straw-bag storage	1.93	1.74	1.58	

Remark 1). Newly harvested rice in 1927.

Comparing the effect of the three methods of storage, Table 11 shows that the viscosity of the paste of rice in straw-bags is smaller than that of rice in the air-tight or carbon dioxide vessels. The viscosity of the paste of rice in the carbon dioxide vessels is somewhat greater than that of the rice in the air-tight vessels. These facts coincide well with the change of the several qualities of boiled rice, as stated already.

9. Damage by insects.

As is well known, several kinds of insects, especially *Calandra oryzae* injures rice heavily and causes its quality to deteriorate in a great degree, when it is stored in the straw-bags. In this study the writers observed the relation between the degree of damage of insects and the methods of storage.

When rice was stored in straw-bags, it was much infested and damaged by insects. The rice in the air-tight vessels or in the carbon dioxide vessels was kept quite free from insects. The writers have counted weevils in one *shō*[1] of the stored rice and at the same time weighed the uninjured perfect grains in 100 g of the stored rice. The results are given in the following table.

1) one *shō* = 1.804 liters

Table 12.

Damage by weevils.

Material	Method of storage	November 1925		November 1926		September 1927	
		Perfect grains in 100 g of rice.	Number of weevils in one shō of rice.	Perfect grains in 100 g of rice.	Number of weevils in one shō of rice.	Perfect grains in 100 g of rice.	Number of weevils in one shō of rice.
		g		g		g	
Shinriki	CO_2 storage	100	0	100	0	100	0
	Air-tight storage	100	0	100	0	100	0
	Straw-bag storage	97.6	46	21.5	2730	14.2	7334
Omachi	CO_2 storage	100	0	100	0	100	0
	Air-tight storage	100	0	100	0	100	0
	Straw-bag storage	98.0	30	30 3	3882	5.0	5596

Table 12 shows, how much weevils thrived and multiplied in the straw-bags and how heavily they injured the rice. The rice in the zinc vessels, on the contrary, was perfectly protected from insects and the rice remained perfectly uninjured. In the beginning of the storage the writers put a great number of weevils into the carbon dioxide vessels, but they found that the insects did not thrive at all. In the other investigation the writers[4] also put weevils into the air-tight vessels with rice, and found they could not live at all. Since the damage of weevils, *Calandra oryzae*, is the most important problem in rice storage, it is very important to keep the insects in check, and from that point of view the writers recommend the use of zinc vessels for the storage of hulled rice. In this experiment the writers observed no difference between the effects of air-tight storage and the carbon dioxide storage.

(Plate II—IV).

10. Germination power of rice.

In October 1927 the effect of storage on germination was studied. It was just three years after harvest. The results of the experiment are given in Table 13.

Table 13.

Germination power of rice.

Material	Method of storage	Germination power	Material	Method of storage	Germination power
		%			%
Shinriki	CO_2 storage	97	Omachi	CO_2 storage	96
	Air-tight storage	97		Air-tight storage	96
	Straw-bag storage	0		Straw-bag storage	0

KONDO[3] reported already that the germination power of the hulled rice in straw-bags is scarcely one year. The above table shows that the rice in straw-bags lost the germination power completely owing to the lapse of three years.

The germination power of unhulled rice in the air-tight storage or in the carbon dioxide storage, on the contrary, was retained perfectly. The germination power of "Shinriki" was 97% and that of "Omachi" 96% and it is just same to that of the new rice. It shows that the rice was preserved perfectly in its quality during the time of storage. (Plate V—VII).

11. Other qualities of rice.

a) Effect of one year storage.

In November 1925 the writers observed that the rice stored in the straw-bags, both kinds of "Shinriki" and "Omachi", one year after the harvest, lost its lustre a little and its surface felt somewhat rough. The rice in the zinc vessels, both the air-tight or carbon dioxide storage, remained, on the contrary, unaltered and had a smooth and lustrous surface.

b) Effect of two years storage.

In November 1926, two years after the harvest, the writers observed that the rice in straw-bags had a rough surface and lost its lustre entirely, its external qualities deteriorated, the damage by insects was serious and the boiled rice could scarcely be eaten. The rice in the zinc vessels, both the air-tight or the carbon dioxide storage, had always a lustrous and smooth surface and its external qualities remained quite unaltered.

c) Effect of three years storage.

In October 1927, three years after harvest, the rice in straw-bags lost the lustre entirely, the damage by insects was serious, and the boiled rice could not be used as food at all. The green colour of the unripe grains faded away. The rice in the air-tight or in the carbon dioxide vessels, on the contrary, had always a good lustre and its qualities remained quite unaltered. The green colour of the unripe grains remained also unaltered.

III. Discussion.

HOWARD[3] stated that Indian wheat thoroughly dried in the sun at harvest time and then immediately put away in air-tight receptacles can be preserved for long periods without injury to its subsequent germination.

DENDY[1] reported on the effect of air-tight storage upon grain insects, using the wheat for the sealing, and summarised its advantages as follows:—

(1) It sterilises the grain by destroying insects in all stages, or other vermin which may be present.

(2) It prevents, absolutely, the access of insects and other vermin.

(3) It prevents even grain with a high moisture content from becoming mildewed.

(4) It prevents even grain with a high moisture content from heating (but it does not prevent the development of acidity, due presumably to anaërobic fermentation, if the moisture content is excessive).

(5) It prevents the absorption of moisture from the atmosphere, so that grain if stored dry will remain dry.

(6) It saves labour and expense by doing away with the necessity for turning the grain over or running it from one silo into another in order to prevent heating.

As above described, according to the writers' experiment, the hulled rice can be preserved in safety, if it is stored in the hermetically sealed vessels, while the hulled rice, which is stored in straw-bags, will be heavily damaged by weevils and the qualities become seriously bad. The results of rice grains quite agree with those of wheat grains. The results of the writers' experiments may be again briefly described as follows.

I. Effect of carbon dioxide storage upon the hulled rice.

The rice grains were not infested by insects and other vermin at all. The grains remained always dry, their volumeweight and hardness increased gradually. The material lost by polishing became smaller. The rice grains, which were stored for three years, germinated 97%. The grains were lustrous and had good qualities. The boiled rice had a good taste, good smell and its colour was quite white. The "*Kamabue*" increased during the time of storage. The viscosity of the rice paste decreased gradually, but yet always greater than that of the other two methods of storage. In short, the hulled rice remained quite unaltered in its qualities and quantity, for the period of the three years.

II. Effect of air-tight vessels upon the hulled rice.

The effect of air-tight vessels upon the hulled rice is just like that of carbon dioxide. The rice grains were absolutely prevented from the access of insects and other vermin, and always remained dry. The volumeweight and the hardness of the grains increased gradually during the period of storage. The material lost by polishing became smaller. After the storage for three years, the grains had the germination power of 97%, the grains were lustrous and their good qualities remained quite unaltered. "*Kamabue*" increased gradually during the time of storage. The boiled rice always tasted good, its smell and colour always remained good. The viscosity of the rice paste decreased gradually, but it was always greater than that of straw-bag storage. In short, the rice was stored in safety, without deterioration of qualities and decrease of quantity.

III. Results of straw-bag storage of the hulled rice.

As the control experiment, the writers have stored the hulled rice, as usual, in straw-bags for three years. The grains were seriously damaged by *Calandra oryzae*. After three years there remained very few grains uninjured. The moisture content of the rice increased quickly, after the commencement of storage, because the thoroughly dried rice absorbed moisture from the atmosphere quickly. The volumeweight of rice decreased very much. The hardness of the grains decreased and became much smaller than that of I and II. The material lost by polishing increased very much. "*Kamabue*" is much smaller than that of I and II. After three years storage, the boiled rice tasted and smelled badly and it was no longer white, but coloured a grayish white. The viscosity of the rice paste became very small. After two years storage the rice could scarcely be eaten, after three years it was quite difficult to be used as food. The above results show that the hulled rice will be in its quantity and quality completely damaged, when it is stored in the straw bags.

IV. Comparison of the results of the three methods of storage.

It is a general belief that the hulled rice may greatly deteriorate in taste and other qualities, when it is stored in a zinc vessel, but it is a mistaken belief. As I and II show, the hulled rice can be preserved for three years or even longer, without deterioration of qualities and decrease of quantity, when it is stored in the air-tight vessel or in the carbon dioxide vessel. The difference of results between I and II is insignificant. Therefore, the air-tight is practically quite enough for the preservation of the hulled rice. But, when the rice is stored in the carbon dioxide vessel, the hardness of rice is greater, the material lost by polishing smaller, the several qualities of the boiled rice better and the viscosity of the rice paste is greater than that of the only air-tight vessel.

As III shows, the rice grains are very soon damaged heavily in regard to both the quality and quantity, when they are stored in the straw-bags. By III the moisture content, volumeweight, hardness of grains, the germination power, the material lost by polishing etc will vary during the period of storage and the changes are quite different from by I and II, and these changes always show the deterioration of qualities.

V. *Conclusion.*

Generally the small farmers of this country have no good granary and their rice is damaged seriously during the time of storage. The writers like to propose to encourage the farmers, who are the greatest percentage of the farmers in Japan, to store rice in large, hermetically sealed zinc vessels. The rice, of course, must be thoroughly dry, and must be stored as soon as possible after the drying at the harvest. Such a simple method of storage would, really bring a great benefit in conserving the rice of this country.

Summary.

1. The writers investigated the effect of air-tight and also the effect of carbon dioxide upon the storage of hulled rice. The hulled rice was divided into three sections and preserved A) in the air-tight vessel, B) in the carbon dioxide vessel and as control C) in the straw-bags.
2. The material of investigations were the hulled rice of "Shinriki" and "Omachi" of 1924. The experiment continued from May 1925 until to day.
3. Every year the weight and volume, moisture, volumeweight, hardness, material lost by polishing, damage by insects, germination power and other qualities of the rice, "*Kamabue*" and several qualities of boiled rice and viscosity of rice paste are particularly investigated.
4. When the hulled rice was stored in a straw-bag, it was heavily damaged by insects, the moisture content increased, the material lost by polishing increased, the taste of boiled rice deteriorated and after two years storage it could not be used as food.
5. When the hulled rice was stored in the hermetically sealed vessel, it was perfectly protected from insects and vermin. The material lost by polishing decreased and the good qualities of the rice remained unaltered. The rice could be preserved with no quantitative and qualitative loss. There was no significant difference between the only air-tight storage and the carbon dioxide storage, but in regard to the hardness, the material lost by polishing, qualities of the boiled rice, the viscosity of rice paste the carbon dioxide storage might be somewhat better than that of the only air-tight storage.
6. In conclusion it would be pointed out the importance of air-tight storage or more carbon dioxide storage as a means of maintaining a reserve of rice in the case of the farmers. It is very important to encourage the farmers to dry the rice thoroughly at the harvest time and to store it in the large zinc vessels. Such a simple method of rice preservation brings a great benefit to the rice economy of this country.

Literature.

1) DENDY, A. and ELKINGTON, H. D., Report on the effect of air-tight storage upon grain insects, Part III, Reports of the Grain Pests (War) Committee, No. 6, Royal Society, 1920.

2) HOWARD, A., Note on the storage of seed. Agricultural Journal of India. Vol. X, Part III. July 1915. Cited in 1.

3) KONDO, M., The storage of rice and change of its physical properties during this period. Ber. d. Ōhara Inst. f. Landw. Forsch. Bd III, Heft 2, S. 153—175, 1926.

4) 近藤，岡村， 米穀の乾燥並に密封と穀象の繁殖及米の蝕害． 糧食研究，第四十四號，昭和二年六月．

PLATE I.

Storage of the hulled rice in the granary of the Ōhara Institute.

I. Air-tight storage in the zinc vessels.

II. Carbon dioxide storage in the zinc vessels.

III. Straw-bags storage.

PLATE II.

(1)

„Shinriki“. The hulled rice grains stored in the straw-bags, 1927.

(2)

„Shinriki“. The hulled rice grains stored in the air-tight vessels, 1927.

PLATE III.

(1)

„Shinriki". The hulled rice grains stored in the carbon dioxide vessels, 1927.

(2)

„Omachi". The hulled rice grains stored in the straw-bags, 1927.

PLATE IV.

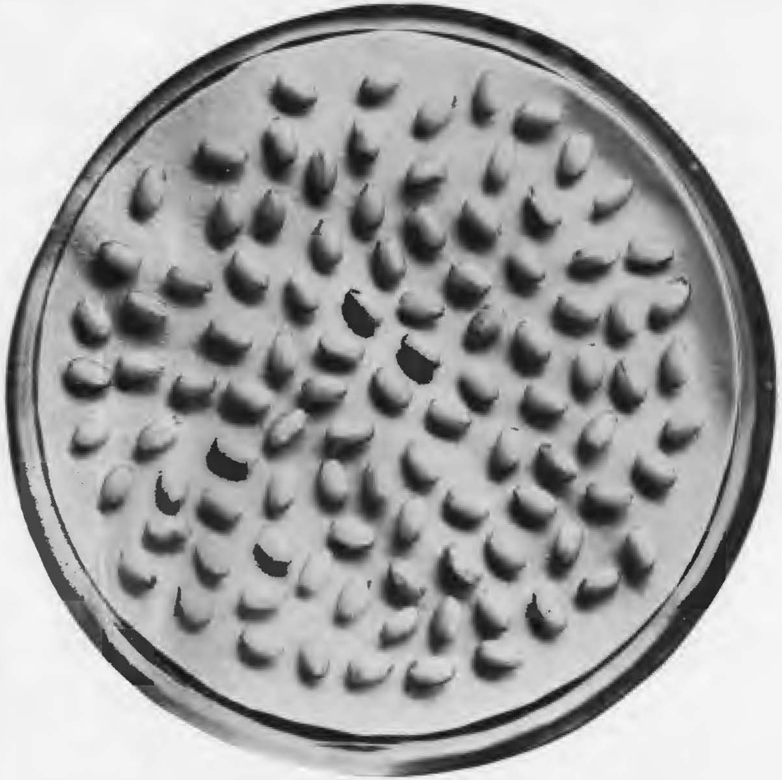
(1)

„Omachi". The hulled rice grains stored in the air-tight vessels, 1927.

(2)

„Omachi". The hulled rice grains stored in the carbon dioxide vessels, 1927.

PLATE V.



(1)

„Shinriki". The hulled rice grains stored in the straw-bags. They lost the germination power at all, 1927.

(2)

„Shinriki". The hulled rice grains stored in the air-tight vessels. They have the germination power of 97%.

PLATE VI.

(1)

„Shinriki". The hulled rice grains stored in the carbon dioxide vessels. They have the germination power of 97%, 1927.

(2)

„Omachi". The hulled rice grains stored in the straw-bags. They lost the germination power at all, 1927.

PLATE VII.

(1)

„Omachi". The hulled rice grains stored in the air tight vessels. They have the germination power of 96%, 1927.

(2)

„Omachi". The hulled rice grains stored in the carbon dioxide vessels. They have the germination power of 96%, 1927.