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Storage of Rice. IX.

Relation between Varying Moisture Content and Change in Quality of Hulled Rice Stored in Containers Air-tight as well as with Carbon-dioxide.

By

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Introduction.

The present authors for a long time have conducted investigations on the storage of hulled rice in air-tight containers as well as in containers with carbon-dioxide. Some of the results[1),2)] already have been reported and attention has been called to the advantages of both methods as means of preserving the grain. When air-tight storage is employed, it is absolutely necessary to dry the rice thoroughly at the harvest time. In the present paper the authors descrive the relation between varying moisture content and physical, physiological and biochemical changes of the hulled rice during air-tight and carbon-dioxide storage extending through three and one half to five years. The purpose of the investigation was to learn the relation between varying moisture content and quality during the time of storage.

I. Materials and Experimental Methods.

As experimental materials hulled rice of two varieties, namely "Omachi" and "Shinriki", were used. The crops were harvested in 1926. Determination of moisture in the lots gave 10, 12, 14, 16 and 18 per cent. The storage was in air-tight zinc containers as well as in zinc containers with CO_2. In the experiment twenty containers were used. (Fig. 1.) The quantity of rice in each container being exactly 2 To*. The storage began on April 19, 1927.

Fig. 1. Storage of hulled rice in air-tight containers as well as in containers with carbon-dioxide.
The storage began in April 1927.

Before storage, the weight and volume of the whole rice, weight of 1,000 grains, moisture, volume weight, hardness of rice, polishing loss and other qualities were determined.

In February, 1928, March, 1929, and May, 1930, the containers were opened and the rice was examined with reference to its physical properties and germinating capacity. At the end of the experiment, after five years, the nutrients, vitamin-B and culinary properties were determined.

In this way, definite conclusions on the effects of varying moisture content upon the physical and physiological, as well as biochemical properties of rice were reached.

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* 2 To = ca 1 bushel.

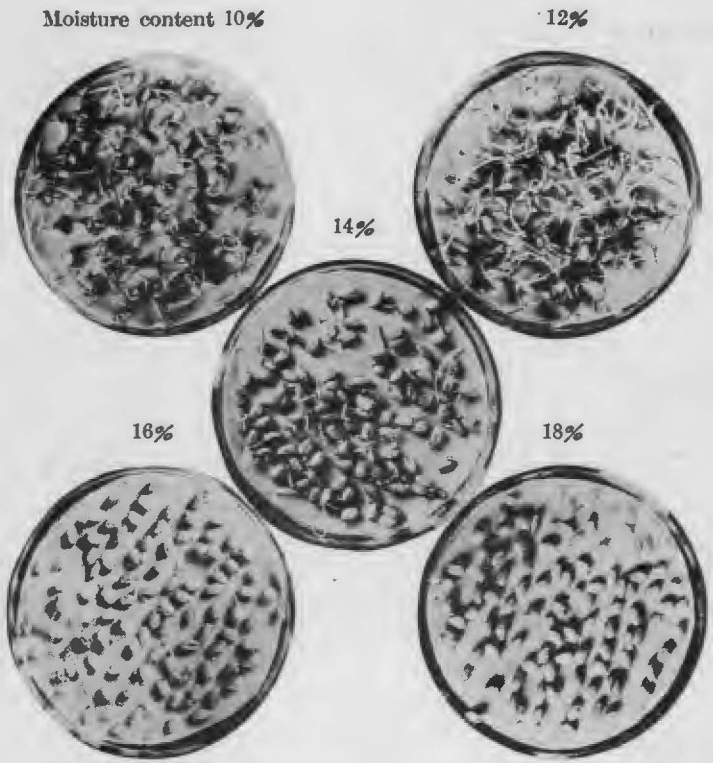

Fig. 2. "Shinriki". The hulled rice kernels stored in the air-tight containers.

The storage began in April 1927.
Germinating experiment in February 1928.

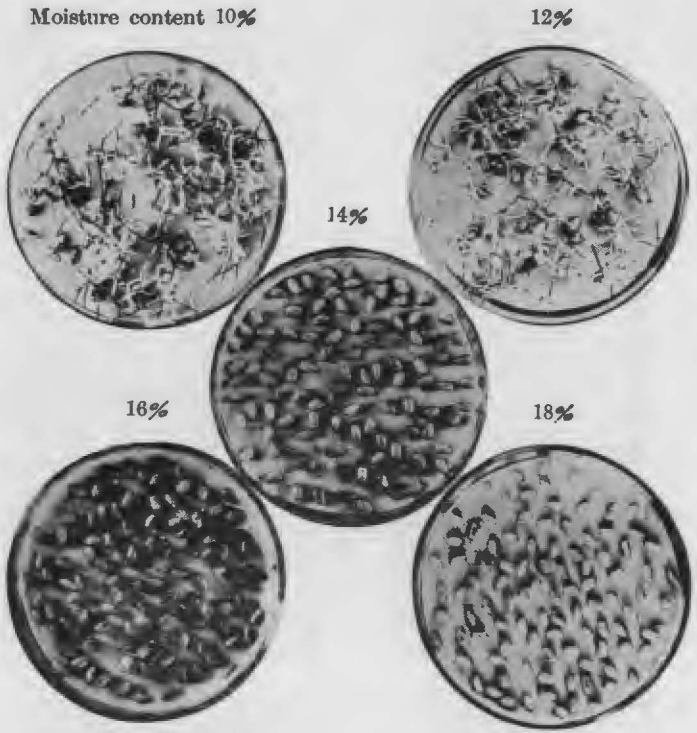

Fig. 3. "Shinriki". The hulled rice kernels stored in the air-tight containers.

The storage began in April 1927.
Germinating experiment in March 1929.

II. Change of Physical Properties of Rice.

1. *Volume and weight of rice.*

A definite portion of the rice in each container was used to measure the volume and weight, which were found to remain quite constant during the period of storage, because the containers were closed air-tight. The weight of 1,000 grains in all cases also was unaltered.

2. *Moisture content of rice.*

Theoretically the moisture content of rice should have remained constant during the period of storage, since the containers were closed air-tight, and tests by the authors showed that such was actually the case for three years, when the moisture content was 10, 12, 14 and 16 per cent, but when it was 18 per cent, there was a slight decrease, because the rice was too wet and evaporation inside the containers took place.

3. *Volume weight of rice.*

During the period of storage, the hectliter-weight of the rice was measured each year and the variation in the volume weight determined. The results are given in Table 1.

Table 1.

Volume-Weight of Hulled Rice (Hectoliter-weight).

Variety	Method of storage	Moisture content	Initial weight in April 1927	February 1928	March 1929	May 1930
		%	kg.	kg.	kg.	kg.
"Shinriki"	Stored in containers with CO_2	10	85.75	86.75	86.12	86.02
		12	85.30	86.15	85.99	85.42
		14	82.52	83.66	82.50	82.60
		16	82.17	83.56	82.17	81.20
		18	80.20	80.57	79.88	77.04
	Stored hermetically	10	85.75	86.86	86.52	86.64
		12	85.30	86.36	85.74	85.68
		14	82.52	83.63	82.57	82.30
		16	82.17	82.37	82.37	79.65
		18	80.20	80.53	79.53	78.18
"Omachi"	Stored in containers with CO_2	10	85.22	86.40	86.08	86.06
		12	84.43	85.99	85.89	85.88
		14	83.10	84.99	85.04	84.16
		16	80.68	82.97	81.58	78.54
		18	78.84	79.56	77.11	74.60
	Stored hermetically	10	85.22	86.83	86.38	86.30
		12	84.43	86.22	85.87	85.69
		14	83.10	85.06	85.05	84.94
		16	80.68	80.90	80.63	80.56
		18	78.84	77.80	77.79	75.60

The above table shows that the volume-weight of the rice with a moisture content of 10, 12 and 14 per cent increased during the time of storage and the quality remained good, but that, the volume-weight of the rice with a moisture content of 16 and 18 per cent generally decreased and the quality deteriorated.

4. *Hardness of rice.*

There are two kinds of hardness. When a grain is broken under pressure, the pressure weight is taken as "resistance to breaking", but when a grain is crushed under pressure, the pressure weight is taken as "resistance to crushing". The resistance is generally denoted in kg. The authors determined the variation in hardness during the time of storage with the following results:

Table 2.

Hardness of Rice.

A. Resistance to Breaking.

Variety	Method of storage	Moisture content	Initial resistance in April 1927	February 1928	March 1929	May 1930
		%	kg.	kg.	kg.	kg.
"Shinriki"	Stored in containers with CO_2	10	11.80	11.40	11.05	11.35
		12	8.87	11.13	8.72	9.48
		14	7.08	7.77	6.87	9.78
		16	5.67	6.38	4.93	4.78
		18	4.26	4.37	4.18	4.16
	Stored hermetically	10	11.80	13.02	11.49	10.91
		12	8.87	10.93	9.29	9.49
		14	7.08	7.69	7.09	6.87
		16	5.67	6.21	4.98	4.65
		18	4.26	4.37	4.20	3.72
"Omachi"	Stored in containers with CO_2	10	9.31	12.75	11.82	11.48
		12	9.31	11.29	10.16	9.70
		14	6.93	7.90	7.79	7.16
		16	5.00	6.43	5.21	4.71
		18	4.41	4.09	4.46	3.56
	Stored hermetically	10	9.31	12.33	11.94	11.14
		12	9.31	10.00	9.33	9.80
		14	6.93	7.99	7.35	7.22
		16	5.00	5.62	4.84	4.11
		18	4.41	3.73	4.45	3.09

B. Resistance to Crushing.

Variety	Method of storage	Moisture content	Initial resistance in April 1927	February 1928	March 1929	May 1930
		%	kg.	kg.	kg.	kg.
"Shinriki"	Stored in containers with CO_2	10	12.40	11.44	11.25	11.79
		12	11.07	11.80	10.02	10.18
		14	8.32	8.69	8.33	7.53
		16	7.76	7.73	7.02	5.81
		18	6.23	6.55	6.48	5.16
	Stored hermetically	10	12.40	13.42	12.01	11.63
		12	11.07	11.44	10.70	10.32
		14	8.32	8.56	8.11	7.71
		16	7.76	7.81	6.52	6.09
		18	6.23	6.25	6.39	5.20
"Omachi"	Stored in containers with CO_2	10	10.79	13.52	12.78	11.87
		12	10.73	12.03	10.98	10.27
		14	9.02	9.10	9.08	80.2
		16	7.51	8.44	7.16	6.44
		18	6.95	5.89	6.47	5.58
	Stored hermetically	10	10.79	13.05	12.45	11.85
		12	10.73	11.58	10.40	10.83
		14	9.02	8.98	9.02	8.85
		16	7.51	7.58	7.32	6.08
		18	6.95	5.85	6.33	5.40

According to the above table, the resistance to breaking of the rice with a moisture content of 10 and 12 per cent increased, but that to crushing was uncertain. In the earlier paper[1], the present authors reported that the hardness of the rice with a moisture content of 11.8 and 11.27 per cent generally increased during 4 years of storage in zinc containers and the rice kept in a good condition. It, therefore may be assumed that the hardness of rice with a moisture content of 10 and 12 per cent in the present experiment increased gradually during the time of storage.

When the moisture content was 14 per cent, the resistance to breaking increased slightly, but that to crushing decreased; when the moisture content was 16 and 18 per cent, the resistance to breaking as well as crushing decreased gradually.

The above data show that, according to the moisture content of the rice, classed as dry or wet, the variations in the two kinds of hardness: (1) resistance

to breaking and (2) resistance to crushing are in opposite directions to each other. The initial hardness differed according to the moisture content and after a lapse of time the difference became much greater.

In the comparison, it seems that the hardness of the rice stored in carbon-dioxide is generally greater than that stored only hermetically. This fact was reported also in the previous paper[1].

5. *Water-absorbing and swelling capacity of rice.*

The authors studied the variation in the water-absorbing and swelling capacity of the several kinds of rice stored three years. Fifty gs. of rice from each zinc containers was soaked in water at 25° to 28°C. for 48 hours, and the percentage of increase in weight and volume noted. Each year this capacity was determined and the following results were obtained :

Table 3.

Swelling and Water-Absorbing Capacity of Water-Soaked Rice.

A. Water-Absorbing Capacity.

Variety	Method of storage	Moisture content	Initial value in April 1927	February 1928	March 1929	May 1930
		%	%	%	%	%
"Shinriki"	Stored in containers with CO_2	10	29.17	29.20	28.90	28.73
		12	25.50	26.62	26.13	24.93
		14	23.83	22.63	22.37	21.98
		16	20.00	20.23	20.48	19.37
		18	18.17	18.20	18.43	17.32
	Stored hermetically	10	29.17	30.52	28.30	28.93
		12	25.50	27.70	26.17	25.27
		14	23.83	22.67	21.88	21.65
		16	20.00	20.20	19.83	19.85
		18	18.17	17.65	18.23	17.57
"Omachi"	Stored in containers with CO_2	10	29.00	29.83	30.05	28.33
		12	28.00	28.02	27.57	25.75
		14	24.50	23.27	23.37	22.27
		16	21.33	20.13	20.08	18.97
		18	18.33	17.92	18.15	17.34
	Stored hermetically	10	29.00	30.37	29.28	29.15
		12	28.00	28.17	27.20	26.58
		14	24.50	23.70	22.83	22.55
		16	21.33	19.80	19.92	19.10
		18	18.33	17.70	18.00	17.25

B. Swelling Capacity.

Variety	Method of storage	Moisture content	Initial value in April 1927	February 1928	March 1929	May 1930
		%	%	%	%	%
		10	40.50	41.05	37.62	37.67
	Stored in containers with CO_2	12	35.36	35.52	35.32	34.89
		14	30.40	30.55	29.88	29.33
		16	28.70	27.95	26.34	25.23
		18	25.35	24.66	22.56	22.05
"Shinriki"		10	40.50	42.63	37.38	36.24
		12	35.36	36.60	34.52	34.66
	Stored hermetically	14	30.40	31.87	29.41	28.87
		16	28.70	29.17	26.93	25.69
		18	25.35	26.73	23.50	21.64
		10	37.85	40.96	38.33	37.62
	Stored in containers with CO_2	12	37.38	37.20	35.55	35.05
		14	33.41	33.26	30.57	30.47
		16	29.00	27.25	26.25	24.94
		18	24.83	23.85	22.64	22.83
"Omachi"		10	37.85	36.99	38.76	37.14
		12	37.38	36.65	35.78	35.51
	Stored hermetically	14	33.41	38.30	30.19	29.40
		16	29.00	27.40	26.35	25.29
		18	24.83	24.60	23.14	23.39

Table 3 shows that, when the moisture content of the rice was 14—18 per cent, the water-absorbing and swelling capacity decreased regularly with the length of time of storage, as was true of rice in straw bags, but when the moisture content was 10 and 12 per cent the capacity increased during the first year, then decreased.

If not dried sufficiently, rice in zinc containers deteriorates like that in straw bags and as a result, the change in water-absorbing and swelling capacity is similar in the two cases. But, if the rice is dried sufficiently, the quality is well preserved in zinc containers, although the change of water-absorbing and swelling capacity is somewhat different from that stored in straw bags.

There is no difference in the variation in the water-absorbing and swelling capacity between rice stored in zinc containers with CO_2 and that stored only hermetically.

6. *Polishing loss.*

The polishing loss of rice with different moisture contents is as shown in the following table:

Table 4.

Variation in Polishing Loss of Rice.

(Results in percentage by weight.)

Variety	Method of storage	Moisture content	Initial polishing loss in April 1927	Feburary 1928	March 1929	May 1930
		%	%	%	%	%
		10	6.67	7.17	7.67	6.80
	Stored in containers with CO_2	12	7.56	7.80	8.92	8.00
		14	9.35	9.58	10.33	9.33
		16	11.20	9.07	10.33	9.46
"Shinriki"		18	12.16	9.85	11.77	10.37
		10	6.67	7.22	7.50	6.23
		12	7.56	7.60	9.00	6.77
	Stored hermetically	14	9.35	9.80	10.05	8.17
		16	11.20	9.45	10.17	8.23
		18	12.16	11.22	11.83	9.77
		10	6.71	7.33	7.50	5.93
	Stored in containers with CO_2	12	7.25	7.37	8.75	7.90
		14	9.14	9.03	10.16	8.23
		16	10.75	9.85	9.33	8.93
"Omachi"		18	12.48	10.72	11.50	9.67
		10	6.71	6.98	7.17	7.47
		12	7.25	7.30	8.67	8.23
	Stored hermetically	14	9.14	9.73	10.50	8.60
		16	10.75	9.73	10.00	10.73
		18	12.48	10.72	11.00	11.07

When the moisture content was 10, 12 and 14 per cent, the polishing loss at the beginning of storage was small, and during the first and second years it increased slightly, but during the third year it decreased ; when, however, the moisture content was 16 and 18 per cent, the polishing loss was initially large, but it decreased during the time of storage. In the preceding paper[1], the authors reported, that the polishing loss of rice with a moisture content of 11.8 and 11.3 per cent in zinc containers, whether stored hermetically or in carbon-dioxide, decreased with the length of time of storage. Therefore it may be concluded, that in general, polishing loss is either unaltered or else decreases during the time of storage, because of increased dryness and hardness of the grains.

The difference in polishing loss between the rice stored in containers with carbon-dioxide and that merely stored hermetically was uncertain. This result does not coincide with that of the preceding experiment[1].

7. "*Kamabue*".

When white rice is boiled in a kettle, its volume increases greatly. The percentage of increase in volume of boiled rice over that of the original volume is called "Kamabue". The authors studied the relation between moisture content and "Kamabue" at the different periods of storage with the following results :

Table 5.

"Kamabue" of the Stored Rice.

Variety	Method of storage	Moisture content	Initial Kamabue in April 1927	February 1928	March 1929	May 1930
		%	%	%	%	%
"Shinriki"	Stored in containers with CO_2	10	107.31	116.61	129.04	135.01
		12	105.22	114.91	126.69	131.61
		14	104.88	112.07	118.19	130.32
		16	102.05	110.27	113.23	126.01
		18	101.75	109.67	109.98	125.00
	Stored hermetically	10	107.31	115.11	131.52	132.71
		12	105.22	114.02	121.75	131.88
		14	104.88	110.07	118.30	131.47
		16	102.05	108.59	114.68	129.82
		18	101.75	108.33	116.83	126.32
"Omachi"	Stored in containers with CO_2	10	107.81	121.65	132.61	134.12
		12	105.61	118.61	120.51	131.49
		14	104.52	118.68	119.66	129.18
		16	104.99	118.10	121.88	127.67
		18	104.04	116.32	118.38	128.29
	Stored hermetically	10	107.81	119.35	132.53	133.37
		12	105.61	118.31	118.33	134.13
		14	104.52	117.11	120.37	131.03
		16	104.99	117.11	120.00	126.25
		18	104.04	115.38	114.24	125.33

According to Table 5, the "Kamabue" increased regularly during storage, without regard to the moisture content or the methods of storage. As is well known, the lower the moisture content, the higher the "Kamabue", and this relationship is unaltered during the time of storage. Moreover it appears that, the more thorough the drying the greater the "Kamabue" increment during storage.

8. *Quality of boiled rice.*

The authors examined the boiled rice with respect to taste, smell, stickiness and colour. The results are shown in a tabular form in Table 6. The notations of taste are as follows:— a.....good, b.....fairly good, c.....slightly changed but yet edible, d.....with bad smell, not edible:

Table 6.

Quality of Boiled Rice.

Variety	Method of storage	Moisture content	February 1928		March 1929		May 1930	
			Taste	Colour	Taste	Colour	Taste	Colour
"Shinriki"	Stored in containers with CO_2	% 10	a	white	a	white	a	white
		12	a	white	a	white	a	white
		14	a	white	b	slightly brownish	c	slightly brownish
		16	b	brownish	c	brownish	d	brownish
		18	c	brownish	d	brownish	d	brownish
	Stored hermetically	10	a	white	a	white	a	white
		12	a	white	a	white	a	white
		14	a	white	b	slightly brownish	c	slightly brownish
		16	b	brownish	c	brownish	d	brownish
		18	c	brownish	d	brownish	d	brownish
"Omachi"	Stored in containers with CO_2	10	a	white	a	white	a	white
		12	a	white	a	white	a	white
		14	a	white	b	slightly brownish	c	slightly brownish
		16	b	brownish	c	brownish	d	brownish
		18	c	brownish	d	brownish	d	brownish
	Stored hermetically	10	a	white	a	white	a	white
		12	a	white	a	white	a	white
		14	a	white	b	slightly brownish	c	slightly brownish
		16	b	brownish	c	brownish	d	brownish
		18	c	brownish	d	brownish	d	brownish

Table 6 shows, that in the case of rice with a moisture content of 10 and 12 per cent, the quality of boiled rice was perfectly good for three and half years after harvest, whereas in the case of rice with a moisture content of 14 per cent, it was good during the first year, but after two years, the taste was slightly off

and the colour was slightly brownish, neverthless the rice was edible. In general, it may be stated, that a moisture content of 14 per cent caused no deterioration during the first year, little during the second year, but somewhat more during the third year.

In the case of rice with a moisture content of 16 per cent, after one year storage, the boiled rice was slightly off flavour, and the colour was brownish; after two years it showed further deterioration, and after three years it was not eatable. The limit of duration of storage of hulled rice with a moisture content of 16 per cent is therefore less than one year.

The deterioration as measured by the quality of boiled rice was still more marked, when the moisture content was 18 per cent. Although after one year, the change in taste was slight, after two years it was sufficient to cause a very bad taste. A brownish colour appeared during the first year.

From the above facts, it may be safe to say, that the maximum length of time allowable for the safe storage of hulled rice in containers with carbon-dioxide, as well as in air-tight containers, is for a moisture content of 10—12 per cent three years and still longer, for 14 per cent one or two years, and for 16—18 per cent less than one year.

It was observed that there was no distinct difference as regards the quality of the boiled rice between the storage in carbon-dioxide and air-tight storage.

9. *Viscosity of rice paste.*

The variation in viscosity of rice paste during the time of storage was studied. The rice paste had the density of 5 per cent (water 100 cc.: rice powder 5 g.) at a temperature of 40°C. Taking the viscosity of water of 40°C. as 1 (standard), the viscosity of the rice paste was determined. The results are given in Table 7.

Table 7.

Viscosity of Rice Paste.

Variety	Method of storage	Moisture content	Initial viscosity in April 1927	February 1928	March 1929	May 1930
		%				
		10		1.913	1.719	1.718
	Stored in containers with CO_2	12		1.876	1.661	1.676
		14	1.921	1.848	1.608	1.549
		16		1.831	1.538	1.543
		18		1.800	1.550	1.532
"Shinriki"		10		1.909	1.694	1.661
		12		1.894	1.643	1.603
	Stored hermetically	14	1.921	1.854	1.609	1.541
		16		1.822	1.558	1.434
		18		1.803	1.546	1.529

Table 7 continued.

Variety	Method of storage	Moisture content	Initial viscosity in April 1927	February 1928	March 1929	May 1930
		%				
		10		2.065	1.723	1.686
	Stored in containers with CO_2	12		1.954	1.656	1.665
		14	2.116	1.921	1.605	1.601
		16		1.896	1.557	1.558
		18		1.833	1.514	1.449
"Omachi"		10		1.983	1.709	1.667
		12		1.923	1.682	1.591
	Stored hermetically	14	2.116	1.905	1.647	1.560
		16		1.880	1.606	1.519
		18		1.851	1.521	1.354

Remark: Viscosity of water of 40°C. = 1.

According to Table 7, the viscosity of rice paste decreased gradually during the time of storage and the decrease could not be avoided, although the rice was thoroughly dried and stored hermetically or in containers with CO_2. The decrease however, increased with an increase in moisture content.

Comparing air-tight storage with carbon-dioxide storage, it was noticed that the viscosity of the rice paste, when the storage was in CO_2, was greater than when in air-tight containers. These facts coincide with those reported in the preceding paper[1].

10. *Quality of rice.*

The quality of rice was as Table 8 shows.

(See Table 8 on next page.)

As Table 8 shows, the quality of the rice with a moisture content of 10 and 12 per cent was, after the storage of three and one half years, quite good; the rice had a good luster, colour and smell, and was practically equal to new rice.

The quality of the rice with a moisture content of 14 per cent, after a lapse of one year, was good, after two to three years still fairly good, but after three and one half years a faintly mouldy odor, also slight changes in luster and colour were noted, neverthless the rice was still of pretty good quality.

Rice with a moisture content of 16 per cent deteriorated within one year, and after a lapse of three and one half years it was faintly mouldy, off colour, dull and luster less.

A moisture content of 18 per cent caused deterioration within one year; after three and one half years the kernels were lustreless, rough on the surface, mouldy, and with a bad smell.

From the above facts it may be concluded, that 13 per cent is the maximum moisture content of hulled rice allowable for safe storage in air-tight containers.

Table 8.

Quality of Rice.

Variety	Method of storage	Moisture content	February 1928	March 1929	May 1930
"Shinriki"	Stored in containers with CO_2	% 10	good	good	good
		12	good	good	good
		14	good	good	faint mouldy, less luster, colour changed a little.
		16	mouldy, faint bad smell, brownish, less luster.	mouldy, lusterless, colour slightly changed.	mouldy, lusterless, colour changed.
		18	very mouldy, bad smell, lusterless, brownish, grains clustered in large balls.	very much mouldy, bad smell, lusterless, colour changed, clustered.	very much mouldy, rough on surface, colour changed.
	Stored hermetically	10	good	good	good
		12	good	good	good
		14	good	colour slightly changed and less luster.	faint mouldy smell, colour slightly changed, less luster.
		16	mouldy, faint bad smell, colour slightly changed, less luster.	mouldy smell, colour slightly changed, less luster.	mouldy smell, colour changed, less luster.
		18	mouldy, bad smell, lusterless, colour changed, clustered in balls.	very mouldy, colour changed, slightly clustered.	very much mouldy, rough on surface, colour changed.
"Omachi"	Stored in containers with CO_2	10	good	good	good
		12	good	good	good
		14	good	good	same with "Shinriki"
		16	same with "Shinriki"	same with "Shinriki"	same with "Shinriki"
		18	same with "Shinriki"	same with "Shinriki"	same with "Shinriki"
	Stored hermetically	10	good	good	good
		12	good	good	good
		14	good	same with "Shinriki"	same with "Shinriki"
		16	same with "Shinriki"	same with "Shinriki"	same with "Shinriki"
		18	same with "Shinriki"	same with "Shinriki"	same with "Shinriki"

III. Change in Germinating Power of Rice.

The relationship between the moisture content and the retention of the germinating power was determined with the following results:

Table 9.

Germinating Power of Rice.

Variety	Moisture content	Method of storage	Germinating Capacity			
			Initial germinating capacity in March 1927	February 1928	March 1929	May 1930
	%		%	%	%	%
"Shinriki"	10	Air-tight storage	99.5	99.5	99.8	99.8
		CO_2 storage	„	99.8	99.8	99.5
	12	Air-tight storage	„	100.0	99.5	65.3
		CO_2 storage	„	100.0	99.8	65.5
	14	Air-tight storage	„	25.3 + 13.5*	0	0
		CO_2 storage	„	13.3 + 29.8*	0	0
	16	Air-tight storage	„	6.0 + 16.5*	0	0
		CO_2 storage	„	1.3 + 3.8*	0	0
	18	Air-tight storage	„	6.0 + 8.8*	0	0
		CO_2 storage	„	0.8 + 4.3*	0	0
"Omachi"	10	Air-tight storage	99.5	96.8	99.5	96.5
		CO_2 storage	„	98.0	99.7	97.7
	12	Air-tight storage	„	99.5	99.8	79.8
		CO_2 storage	„	99.5	99.5	83.5
	14	Air-tight storage	„	50.5 + 14.0*	0	0
		CO_2 storage	„	34.8 + 26.8*	0	0
	16	Air-tight storage	„	35.3 + 9.0*	0	0
		CO_2 storage	„	31.8 + 11.0*	0	0
	18	Air-tight storage	„	3.0 + 3.8*	0	0
		CO_2 storage	„	0.5 + 0.8*	0	0

Note: *.....+.....in 1928 shows that the embryos were still alive but much weakend and could not germinate.

From Table 9 it may be seen that, the rice with a moisture content of 10 and 12 per cent retained entirely its germinating capacity after three and one half years from harvest and in this respect was fully equal to new rice. This fact coincides with that given in the preceding report.

When the moisture content was 14 per cent, half or more of the germinating capacity was lost after one year and five months from harvest. After two years from harvest, tne germinating capacity was entirely lost. Obviously the moisture content was too high, if retention of the germinating capacity is desired.

A moisture content of 16 and 18 per cent during one year from harvest caused a large, and during two years a complete loss of germinating capacity.

Comparing air-tight storage with that in carbon-dioxide, if the moisture content is 10 and 12 per cent, there is no distinct difference in the retention of the germinating capacity, but if the moisture content reaches 14—18 per cent, air-tight storage appears to be more advantageous, although a final decision should be reserved pending further experiments.

In the authors' opinion, the germinating capacity of rice shows the condition after storage. If the germinating capacity is completely retained, it indicates that the rice has preserved perfectly its valuable properties, but if the germinating capacity is entirely lost, the quality must be much deteriorated. As the foregoing results show, a moisture content of 13 per cent is the maximum for safe storage during many years. Rice with a moisture content of 12 per cent kept a good condition, but that with a moisture content of 14 per cent eventually deteriorated. In pratice, however, the moisture content of 14 per cent is suitable for one year storage. For storage during several years, the rice must be dried to a moisture content of 13 or better to 12 per cent and stored in a container hermetically.

IV. Biochemical Changes of Rice.

1. *Analyses of rice.*

Rice of a different moisture content stored four years was analysed in July—October, 1930, and the following data (Table 10) were obtained. As the control, the new rice harvested in the autumn of 1929 was used.

(See Table 10 on next page.)

The points brought out in the above table are as follows:

1) When the rice had an initial moisture content of 10—16 per cent, there was no definite gain or loss of moisture during the time of storage, because the containers were sealed air-tight; when, however, the moisture content was 18 per cent, the excessive amount of this constituent was responsible for a slight loss by evaporation inside the containers. It shows that rice of a high moisture content such as 18 per cent, must not be sealed in containers, but must be stored in the open.
2) The percentage of ash was unaltered during the time of storage regardless of the moisture content.
3) The percentage of crude fiber, as well as of fat seems to decrease during the time of storage, when the moisture content is high.

Table 10.

Composition of Rice Stored Four Years.

Variety	Method of storage	Moisture content		In the dry substance				
		Initial	After storage	Ash	Crude fiber	Fat	Crude protein	Carbo-hydrate
		%	%	%	%	%	%	%
"Shinriki"	Stored in containers with CO_2	10.72	10.70	1.43	1.30	2.62	8.08	85.09
		12.62	12.62	1.37	1.29	2.64	8.16	84.86
		14.14	14.14	1.32	1.27	2.61	8.16	84.80
		16.14	16.12	1.43	1.25	2.41	8.13	84.81
		18.00	17.50	1.43	1.22	2.43	8.03	84.61
	Stored hermetically	10.72	10.70	1.28	1.32	2.61	8.24	85.18
		12.62	12.60	1.35	1.33	2.62	8.13	84.85
		14.14	14.20	1.36	1.27	2.46	8.09	85.07
		16.14	16.20	1.34	1.22	2.36	8.12	84.93
		18.00	17.26	1.37	1.22	2.27	8.21	84.62
"Omachi"	Stored in containers with CO_2	10.74	10.74	1.33	1.28	3.20	8.53	85.81
		12.08	12.00	1.40	1.22	3.03	8.57	85.61
		14.00	14.00	1.40	1.18	2.93	8.54	85.59
		16.14	16.14	1.34	1.21	2.93	8.12	85.47
		18.02	17.22	1.39	1.11	2.70	8.44	85.43
	Stored hermetically	10.74	10.74	1.47	1.32	3.17	8.36	85.87
		12.08	12.08	1.44	1.31	3.02	8.55	85.77
		14.00	14.00	1.37	1.32	2.84	8.44	85.66
		16.14	16.10	1.38	1.17	2.84	8.40	85.68
		18.02	17.80	1.29	1.09	2.53	8.27	85.49
"Shinriki"	New rice of 1929, control		17.39	1.36	1.39	2.68	8.49	86.93
"Omachi"	" " " " "		17.57	1.44	1.39	2.65	8.43	85.33

Note: Protein .....N×6.25. KJELDAHL method.
Fat.....SOXHLET method.
Carbohydrate .....LIBERMANN and BERTRAND method.
Crude fiber.....HENNEBERG and STOHMANN method.

4) The percentage of crude protein, as well as of carbohydrates, did not change during the time of storage, regardless of the moisture content; excepting a slight loss of carbohydrates, when the moisture content was too high.

5) A comparison of the percentages of the nutrients in rice stored air-tight and that stored in carbon-dioxide brings out no definite difference attributable to the method of storage.

6) In general it appears that the percentage of nutrients does not change materially during storage in containers hermetically sealed or in carbon-

dioxide. The percentage of fat and fiber, however, seem to be slightly decreased, if the moisture content is 14 per cent or more.

7) In conclusion it may be stated that if rice is dried to a moisture content of less than 13 per cent, the percentages of nutrients will be retained unaltered during four years or perhaps longer.

2. *Activity of catalase.*

The authors studied the catalase activity of rice, just three and one half years after harvest, following the method of HIGUCHI. From each lot of rice, 50 grains of hulled rice were removed and the percentage of hydrogen proxide decomposed by the catalase was determined by titration with potassium permanganate. A comparison was made with that of new rice of 1929. The results are given in Table 11.

Table 11.

Percentage of Hydrogen Peroxide Decomposed by Catalase in Hulled Rice in March 1930.

Lot of rice \ Variety / Method of storage	"Shinriki"		"Omachi"	
	Air-tight storage	In carbon-dioxide	Air-tight storage	In carbon-dioxide
	%	%	%	%
Rice of a moisture content of 10%	66.42	61.99	76.23	70.37
„ „ „ „ „ „ 12%	66.42	61.62	71.91	69.14
„ „ „ „ „ „ 14%	19.56	15.13	38.27	26.23
„ „ „ „ „ „ 16%	19.37	25.83	25.93	20.06
„ „ „ „ „ „ 18%	22.69	29.15	33.33	29.01
Control (new rice)	97.30		97.30	

According to Table 11, the catalase activity of the hulled rice decreased after three and one half years and the higher the moisture content, the more marked was the decrease in catalase activity. In rice with a moisture content of 10 and 12 per cent, the catalase activity was relatively well retained, but in that with a moisture content of 14 per cent or more, the catalase activity decreased, a great difference between lots containing 12 per cent and 14 per cent of moisture being noticeable. From the view point of catalase activity, 13 per cent must be the limit of moisture content for the safe storage of hulled rice for several years.

Comparison of the results show that the catalase activity of rice stored air-tight was often a little greater than that of rice stored in carbon-dioxide.

3. *Glucose and dextrin in rice.*

In November, 1932, the authors determined the content of water soluble glucose and dextrin in rice stored 5 years. The results are given in Table 12.

Table 12.

Glucose and Dextrin in Rice (Nov. 1932).

Moisture content of rice	"Omachi"				"Shinriki"			
	CO_2-storage		Air-tight storage		CO_2-storage		Air-tight storage	
	Glucose	Dextrin	Glucose	Dextrin	Glucose	Dextrin	Glucose	Dextrin
%	%	%	%	%	%	%	%	%
10	0.413	2.293	0.596	2.635	0.403	2.958	0.418	3.238
12	0.468	2.193	0.610	2.418	0.567	2.647	0.593	2.297
14	0.629	1.957	0.627	1.809	0.617	2.117	0.629	2.194
16	0.662	1.867	0.665	1.377	0.679	1.591	0.644	1.619
18	0.571	1.659	1.541	0.241	0.802	1.458	0.562	0.497
New rice of 1932 (control)	0.882	2.515	0.882	2.515	0.798	2.916	0.798	2.916

Table 12 shows that the water soluble glucose decreased in the lapse of 5 years from harvest, the decrease being greater, in lots with a lower moisture content. The dextrin also decreased, but the decrease was greater, the higher the moisture content. A comparison of the results on total soluble carbohydrates (glucose plus dextrin) shows a greater loss, the higher the moisture content. Comparing the results on the rice stored in the two ways no distinct difference in the amount of glucose and dextrin due to the kind of storage was established.

4. *pH value in rice.*

In November, 1932, just after 5 years from harvest, pH values in the rice were determined by the ordinary method using the quinhydrone electrode. A portion of 10 gs. of rice powder was mixed with 50 cc. of distilled water, kept at 25°C. one hour, and the filtered solution used for the determination. The results are given in Table 13:

(See Table 13 on next page.)

According to Table 13, the pH of the rice with a moisture content of 10 and 12 per cent was unaltered after a lapse of 5 years from harvest, but that of the rice with a moisture content of 14 per cent or more decreased and its decrease was greater the higher the moisture content. There was no difference in pH between the lots stored in CO_2 and air-tight.

In the case of the new rice or rice stored in a good condition, the solution was always faintly alkaline, but in the case of the rice, that hat deteriorated in quality during storage owing to a high moisture content, it became faintly acid. By the determination of pH it may, therefore, readily be learned whethere any change in quality occured during the period of storage.

Table 13.

pH in Rice (Nov. 1932).

"Omachi"			"Shinriki"		
Lot of hulled rice		pH	Lot of hulled rice		pH
New rice harvested in 1932 (control)		7.8	New rice harvested in 1932 (control)		7.7
Hulled rice stored in CO_2	Moisture content of 10%	7.8	Hulled rice stored in CO_2	Moisture content of 10%	7.8
	" " " 12%	7.4		" " " 12%	7.8
	" " " 14%	7.1		" " " 14%	7.0
	" " " 16%	6.8		" " " 16%	7.1
	" " " 18%	6.6		" " " 18%	7.2
Hulled rice stored air-tight	Moisture content of 10%	7.8	Hulled rice stored air-tight	Moisture content of 10%	7.8
	" " " 12%	7.6		" " " 12%	7.8
	" " " 14%	7.2		" " " 14%	7.2
	" " " 16%	7.1		" " " 16%	6.9
	" " " 18%	6.6		" " " 18%	6.5

V. Vitamin-B.

The preservation of vitamin-B in the different lots of hulled rice during storage was studied. Each experiment was repeated twice. As experimental animals young White Leghorn were used.

Experiment I.

The first experiment was carried out in July, 1930. A set of two fowls was used for each kind of rice. During the time of the experiment each fowl was fed with a ration composed of rice powder, Osborne-salts, casein, and cod liver oil. A set of fowls was fed, as a control, with a cleaned polished rice, but in the experiment 50 per cent of the hulled rice was added to cleaned polished rice or 100 per cent of the hulled rice in question was used. The fowls, which were exclusively fed on polished powdered rice, owing to the deficiency of vitamin-B, lost their appetite sooner or later, suffered a kind of neuritis, and died. In the case of the rice under investigation, the greater the content of vitamin-B, the longer the illness was defered and the longer the fowl lived. Conversely if vitamin-B decreased in content, the illness and death occurred sooner. During the time of the experiment, the daily weight of the fowls, the latent period of

illness, that is the period from the beginning of the experiment to the time of attack, and the duration of life, that is from the beginning of the feeding experiment to the time of death, were determined. From these data the content of vitamin-B in rice also can be approximately determined. The results of the feeding experiment are given in Table 14.

Table 14.

Results of Feeding Experiment in July 1930.

Rice		50% of hulled rice added		100% of hulled rice	
		Latent period of illness	Duration of life	Latent period of illness	Duration of life
White rice only		4.5 days	8.8 days	4.5 days	8.8 days
"Shinriki" stored in CO_2	Moisture content of 10%	14.0 „	17.0 „	24.5 „	30.5 „
	„ „ „ 12%	14.0 „	21.0 „	18.5 „	27.0 „
	„ „ „ 14%	14.0 „	19.0 „	14.0 „	24.0 „
	„ „ „ 16%	14.0 „	18.5 „	18.0 „	31.5 „
	„ „ „ 18%	18.0 „	24.5 „	26.0 „	35.0 „
"Shinriki" stored air-tight	Moisture content of 10%	14.5 days	24.5 days	20.5 days	27.0 days
	„ „ „ 12%	17.5 „	25.5 „	13.5 „	21.0 „
	„ „ „ 14%	16.0 „	24.0 „	15.5 „	28.0 „
	„ „ „ 16%	16.5 „	23.5 „	—	alive
	„ „ „ 18%	19.0 „	25.0 „	—	alive
"Omachi" stored in CO_2	Moisture content of 10%	15.5 days	26.5 days	26.0 days	30.5 days
	„ „ „ 12%	15.0 „	23.0 „	18.5 „	23.5 „
	„ „ „ 14%	12.0 „	20.5 „	14.0 „	24.5 „
	„ „ „ 16%	10.5 „	18.5 „	20.0 „	34.0 „
	„ „ „ 18%	15.0 „	24.5 „	20.5 „	31.5 „
"Omachi" stored air-tight	Moisture content of 10%	15.0 days	34.0 days	24.5 days	29.0 days
	„ „ „ 12%	14.5 „	26.5 „	18.0 „	29.0 „
	„ „ „ 14%	9.5 „	15.0 „	16.5 „	28.5 „
	„ „ „ 16%	13.0 „	25.5 „	14.5 „	24.5 „
	„ „ „ 18%	15.5 „	24.5 „	19.5 „	31.5 „

According to Table 14, it may be seen that in the case of the rice with a moisture content of 10—14 per cent, the lower the moisture content, the longer

the latent period of illness and the life of the fowls, hence the lower the moisture content, the higher the vitamin-B content. In the case of rice with a moisture content of 16—18 per cent, the reverse was true, namely, the higher the moisture content, the higher also the vitamin-B content. It is of interest that the vitamin-B content was higher, when the moisture content was 18 per cent than when it was 10—14 per cent. In the opinion of the authors, this correlation of high moisture and vitamin-B content is caused by moulds, which grew on the grain with the higher percentage of moisture.

The difference in vitamin-B content between the rice of air-tight storage and that stored in carbon-dioxide was not distinct.

Experiment 2.

In November, 1931, the vitamin-B experiment was repeated and the relationship between the moisture content and vitamin-B content was determined. The rice was harvested in 1926, that is 5 years previously. Owing to the deficiency of the materials, a mixture of half "Shinriki" and half "Omachi" was used. In each experiment, 50 per cent of the hulled rice in question was added to clean polished rice. The method followed was the same as in Experiment 1. The results of the feeding experiment are given in Table 15.

Table 15.

Results of the Feeding Experiment in November, 1931.

50 per cent of hulled rice added to clean polished rice.

Rice		Latent period of illness	Duration of life
White rice only		5.3 days	7.8 days
New rice of 1931, of a moisture content of 14% (control)		9.3 „	20.3 „
Rice stored in CO_2	Moisture content of 10% ...	9.8 days	20.5 days
	„ „ „ 12% ...	9.8 „	18.8 „
	„ „ „ 14% ...	8.5 „	15.3 „
	„ „ „ 16% ...	8.5 „	14.8 „
	„ „ „ 18% ...	6.8 „	9.5 „
Rice stored air-tight	Moisture content of 10% ...	9.3 days	20.3 days
	„ „ „ 12% ...	8.8 „	18.5 „
	„ „ „ 14% ...	8.5 „	14.3 „
	„ „ „ 16% ...	9.3 „	18.0 „
	„ „ „ 18% ...	13.5 „	21.5 „

From the above table it is evident that, if the moisture content of rice increases, its vitamin-B content decreases gradually during the time of storage and as a result, the latent period of beri-beri and the duration of life of fowls also decreases gradually. The comparative vitamin-B values were calculated by

the formula of MOARI and OGATA[3]. Expressing the quantity of vitamin-B in the control lot of 1931 as equal to 100, the calculated quantities of vitamin-B in the 10 lots of different moisture content were as given in Table 16.

Table 16.

Comparative Values of Vitamin-B in the Hulled Rice of Different Moisture Content.

Method of storage	Stored in CO_2					Stored air-tight					New rice (control)
Moisture content	10%	12%	14%	16%	18%	10%	12%	14%	16%	18%	
Comparative vitamin-B vaule	107.0	107.0	88.4	88.4	51.2	100.0	93.0	88.4	100.0	141.9	100.0

Tables 15 and 16 show the following facts:

When the moisture content of the rice was 10 per cent, the vitamin-B did not decrease at all even after the lapse of 5 years from harvest. The stored grain was equal to new rice.

When the moisture content of the rice 12 per cent, the vitamin-B did not decrease at all or decreased only a little, even after the lapse of 5 years from harvest. The results show that the rice was in a good condition after storage.

In the case of rice with a moisture content of 14 per cent compared with new rice, the vitamin-B decreased 12 per cent after the lapse of 5 years from harvest. This result coincides with the decrease in the germinating power and shows that the moisture content of 14 per cent was rather too much for safe storage.

Rice with a moisture content of 16 per cent stored in CO_2 during 5 years also lost about 12 per cent of its vitamin-B, but that of the same moisture content stored merely air-tight during 5 years lost apparently none. In the opinion of the authors, there must be a gradual loss of vitamin-B during the time of storage, but owing to the growth of moulds the gain is more than offset.

The rice with a moisture content of 18 per cent stored in CO_2 during 5 years lost vitamin-B equivalent to half that in the new rice; however, when stored air-tight, its vitamin-B increased due doubtless to moulds on the grains.

Comparison show no distinct difference in the vitamin-B content between the CO_2-stored and the air-tight stored rice, with the exception of the lots with a moisture content of 16—18 per cent, in which cases the gain is attributable to moulds.

VI. Conclusion.

In the present paper the effect of the varying moisture content of hulled rice stored air-tight or in carbon-dioxide upon the quality was studied and the most suitable moisture content was determined.

With respect to the various properties namely, physical, chemical, and physiological, a moisture content of 10 per cent or 12 per cent was well suited for the safe storage of hulled rice for a long time under climatic conditions like those of Okayama Prefecture, a moisture content of 14 per cent was allowable for one year storage; but as a moisture content of 16 and 18 per cent was excessive, 13 per cent accordingly is adopted as the allowable limit of moisture, if the rice is designed for storage.

There was no distinct difference in the quality of rice between that in air-tight and carbon-dioxide storage. It is sufficient, therefore, to store rice in hermetically sealed containers and quite unnecessary to resort to the additional precaution of displacing the air with carbon-dioxide gas.

Summary.

1) The hulled rice of "Shinriki" and "Omachi" harvested in 1826 with a varying moisture content, namely 10, 12, 14, 16 and 18 per cent was stored in air-tight containers as well as in containers with carbon-dioxide during 5 years and the effects of the varying moisture content upon the quality of rice was studied.

2) During the period of storage, each year the volume and weight, moisture content, weight of 1,000 grains, volume weight, hardness, water absorbing and swelling capacity, polishing loss, "Kamabue", quality of boiled rice, viscosity of rice paste, general quality and germinating power, and, at the end of the experiment, nutrients, catalase activity, pH value and vitamin-B content were determined.

3) The volume and weight of the whole rice as well as the weight of 1,000 grains always remained unaltered during the period of storage, because the containers were closed quite air-tight.

4) The moisture content of the rice with an initial content of 10, 12, 14 and 16 per cent was in all cases constant during three years, but that of rice with an initial content of 18 per cent decreased a little, because the excessive moisture caused a slight evaporation inside the containers.

5) The volume-weight of the rice with a moisture content of 10, 12 and 14 per cent increased during the time of storage, but that of the rice with a moisture content of 16 and 18 per cent generally decreased.

6) When the moisture content was 10 and 12 per cent, the hardness appeared to increase during the time of storage, when the moisture content was 14 per cent, the resistance to breaking increased a little, but that to crushing decreased, and when the moisture content was 16 and 18 per cent, the resistance to breaking as well as crushing decreased gradually.

7) When the moisture content was 10 and 12 per cent, the water absorbing and swelling capacity increased in the first year, then decreased; when the

moisture content was 14—18 per cent, the capacity decreased gradually from the first year to the end of the time of storage.

8) The polishing loss of rice stored hermetically as well as in carbon-dioxide was unaltered or else decreased during the time of storage, because of the gradual drying and hardening of the grains. This was always true regardless of the percentage of moisture.

9) The "Kamabue" of rice increased regularly during storage, regardless of the moisture content as well as whether stored air-tight or in carbon-dioxide. The more the rice was dried, the greater "Kamabue" increase during storage.

10) As regards the quality of the boiled rice, it may be stated that the maximum length of time allowable for the safe storage of hulled rice in air-tight containers or in containers with carbon-dioxide was for 10—12 per cent of moisture three years and still longer, for 14 per cent of moisture one or two years and for 16—18 per cent of moisture, less than one year.

11) The viscosity of rice-paste decreased gradually during the time of storage, although the rice was thoroughly dried and stored hermetically or in containers with CO_2. The higher the moisture content, the greater the decrease in the viscosity of the rice-paste. Rice stored in CO_2 yielded a paste of higher viscosity than that stored in air-tight containers.

12) After storage three and one half years, the rice with a moisture content of 16 and 18 per cent became mouldy and had a bad smell, but that with a moisture content of 10 and 12 per cent was kept in good condition and that with a moisture content of 14 per cent kept fairly well. The maximum moisture content of hulled rice allowable for safe storage in a air-tight container is 13 per cent.

13) As regards the germinating capacity of rice, a moisture content of 13 per cent is the maximum for safe storage during several years. In practice, however, a moisture content of 14 per cent is not too high for one year storage.

14) If rice is dried to a moisture content of less than 13 per cent and stored hermetically, the percentage of nutrients will be retained unaltered during three years or perhaps longer, but, if the moisture content is 14 per cent or more, some decrease in nutrients will occur. No distinct difference in the percentages of the nutrients between rice stored air-tight and that stored in CO_2 was established.

15) The catalase activity of hulled rice decreased after three and one-half years and the higher the moisture content, the more marked the decrease. In point of catalase activity, 13 per cent must be regarded as the maximum moisture content for safe storage for several years.

16) Glucose and dextrin in rice decreased in a great degree during the time of storage. When the moisture content was higher, the decrease in glucose plus dextrin was greater. There was no distinct difference in the percentages of glucose and dextrin between air-tight and CO_2-storage.

17) The pH value of rice with a moisture content of 10 and 12 per cent was unaltered after a lapse of 5 years from harvest and the solution was always faintly alkaline, but when the moisture content was 14 per cent or more the pH value decreased. When the moisture content was high, the decrease was large and the solution became faintly acid. There was no difference in pH values between the rice stored in CO_2 and merely in air-tight containers.

18) When the initial moisture content was 10 to 12 per cent, the vitamin-B did not decrease at all, during 5 years from harvest; when the moisture content was 14 per cent, the vitamin-B decreased 12 per cent, when the moisture content was 16—18 per cent, the vitamin-B decreased as a rule, but owing to the growth of moulds on the grains, in some cases it actually increased.

19) Considering all the chemical, physical, biological and culinary properties of hulled rice, it may be said in conclusion, that 13 per cent is the allowable limit of moisture for storage in Okayama Prefecture and it is sufficient to store merely in hermetically sealed containers, the use of carbon-dioxide being quite superfluous.

Literature.

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