

Storage of Rice. XIX.

Removal of Moisture from Hulled Rice by Heated Air.

By

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I. Introduction.

For the safe storage of rice, the desiccation of the rice itself is the most important consideration. There are, of course, many ways whereby the rice can be dried. Among others, the desiccation of the unhulled rice (paddy) itself at harvest time, by exposure to the sun or by heated air, is most common.

It is very often necessary, however, to desiccate the underdried hulled rice. As is well known, the desiccation of hulled rice is very difficult, because the rice easily becomes cracked and its lustre lost. As a result, it becomes very unprofitable to sell this rice.

As one of the methods of desiccation of the underdried hulled rice, large tin containers, containing receptacles of desiccating materials, such as CaCl_2 or CaO , can be used, since the materials absorb the moisture from the rice during storage. The effects of the desiccating materials on hulled rice were studied, in repetition, in the preceding experiments^{1), 2), 3)}, and it was noticed that this method of desiccation may be recommended to the farmers throughout the whole of Japan.

However, big farmers, landlords or the government, always store the underdried hulled rice in great quantities for a long time. In such cases the hulled rice must be desiccated on a rather large scale by the sun, or by heating. However, desiccation of hulled rice is not carried out in general, because, as described above, the rice becomes easily cracked and deteriorates in general quality. One needs, therefore, to investigate this problem further. On the removal of moisture in the hulled rice by a desiccating material, the authors have already published several papers¹⁾⁻⁴⁾. In the present paper the results of desiccation by heated air are reported, which were carried out in 1935, 1936 and 1937 at the Ōhara Institute.

II. Experiments in 1935.

In 1935 the authors conducted experiments on the desiccation of the hulled rice, employing a drying machine. The apparatus is specially constructed for the drying of rice, as well as barley and wheat. It is called "Kanaoka Heat Drying

Machine". For the sake of these experiments the apparatus was constructed on a rather small scale, the capacity being three *Koku**. The chamber was filled with rice and heated air was blown into it. The air was heated by a heater with "Rentan"-coal. (Plate I.)

The temperature of the air blown into the apparatus was so adjusted as to be highest at the beginning of the process and to decrease gradually in the course of drying. The temperature of the rice changed according to the temperature of the air in the chamber. If the temperature of the heated air became too high, the rice became overheated and cracked.

In 1935 six experiments, in replica, were conducted; the effects of different temperatures of heated air, namely 25.5–55°C., on hulled rice with a moisture content of 15 or 16 per cent, being investigated. In the present paper, only two experiments of these will be described in detail, the others being omitted because the results were similar.

Experiment A.

1. Materials and Methods:

In the preliminary experiments it was demonstrated that, when the temperature of rice was kept to 23°C. or lower, the percentage of cracked kernels was small, and that, when the rotating movement of kernels in the apparatus was checked, the kernel surface always remained smooth and lustrous. Moreover, the drying was very effective at these temperatures. Accordingly, the present experiment was carried out in the following way: The temperature of the heated air blown into the dryer was varied during the operation. At the beginning of the drying process, the temperature was kept at 40°C. and was kept at this temperature for one hour. After this hour, the temperature was lowered to 35°C. and was kept at this temperature for one hour. Then the temperature was again lowered, to 30°C. this time, and kept at this temperature for three hours. The drying experiment began at 9:30 a.m. and ended at 2:30 p.m., a total of five hours. The temperature of the rice during the experiment was between 22 and 23°C. The rotating movement of rice was so regulated that at ten-minute intervals the rice was slowly rotated for one and one-half minutes. As material, hulled rice with a moisture content of 15 per cent was employed. The experiment was carried out on April 1, 1935.

2. Results:

The results of the desiccation experiment of rice kernels is presented in Table 1.

As will be seen in Table 1, the desiccation of the rice was successful, since the moisture content of rice was decreased from 15 per cent to 12.9 per cent, the number of cracked kernels increased very little and the number of broken kernels did not increase at all. The volume-weight of rice remained unaltered. The

* One *Koku* = 0.18 kilolitre.

roughness of kernel surface, which is caused by friction with the apparatus, did not increase at all. The colour of the rice remained unaltered, but a little of the lustre of the kernels was lost. The total volume of rice decreased 2 per cent, this being the natural results of desiccation. The results of the present experiment were satisfactory, but the problem of how to check the loss of lustre remained.

Table 1.
Results of Desiccation of Hulled Rice by Heated Air.

April 1, 1935, weather clear, atmospheric temperature at 9.30 a.m. 8.9°C.

Time	9.30 a.m.	10.30 a.m.	11.30 a.m.	0:30 p.m.	1.30 p.m.	2.30 ^o p.m.
Temperature of heated air . . . °C.	40	40	35	30	30	30
Temperature of the hulled rice . °C.	8.0	23.5	23.0	22.5	22.5	22.2
Moisture content of rice %	15.0	14.9	14.2	13.6	13.2	12.9
Cracked kernels (in weight) . . . %	10.8	11.2	11.5	11.8	12.0	12.4
Broken kernels (in weight) . . . %	0.2	0.2	0.2	0.2	0.2	0.2
Volume-weight (g. / $\frac{1}{4}$ L.)	210.0	210.0	209.7	209.5	209.5	209.6
Roughness of the surface caused by friction	ordinary	ordinary	ordinary	ordinary	ordinary	ordinary
Lustre of the surface	"	"	"	{ a little less lus- terous	{ a little less lus- terous	{ a little less lus- terous
Colour	"	"	"	ordinary	ordinary	ordinary

Experiment B.

In order to find a practical method of checking the loss of lustre of the kernels during desiccation, the present experiment was conducted in the following way:—

1. Materials and Methods:

Hulled rice with a moisture content of 15.1 per cent was employed. In this experiment 2 *Koku* of the hulled rice was mixed with 1.2 *Koku* of rice chaff, with the expectation that by this means the friction of kernels with the apparatus could, to some degree, be checked. When chaff is mixed with the kernels, the heated air easily penetrates between the kernels and as a consequence the temperature of the rice can be raised quickly. In the present experiment, therefore, the temperature of the heated air blown into the apparatus was lower than that in the preceding experiment. During the first hour the temperature of the heated air was kept at 35°C., during the next hour at 30°C., during the third hour at 28°C., during the fourth hour at 27°C., and during the last two hours at 25.5°C. The rice was brought into motion for one minute every 10 minutes. The temperature of rice was so controlled as to be 22–23°C. The desiccation experiment

of rice should have rather been carried out in winter, because the rice can be dried at a relatively lower temperature then. If the temperature becomes high, the rice easily becomes cracked. The present experiment was carried out in April 22, 1935 ; this is too late for such desiccation.

2. Results :

The results of the experiment are given in Table 2.

Table 2.

Results of Desiccation by Heated Air of Hulled Rice Mixed with Chaff.

April 22, 1935, weather clear, atmospheric temperature at 10 a.m. 8.2°C.

Time	10 a.m.	11 a.m.	12 a.m.	1 p.m.	2 p.m.	3 p.m.	4 p.m.
Temperature of heated air . . . °C.	35	30	28	27	25.5	25.5	25.5
Temperature of the hulled rice . °C.	14.7	22.5	23.0	22.5	22.0	21.8	21.5
Moisture content of rice %	15.1	14.8	14.3	13.9	13.7	13.6	13.5
Cracked kernels (in weight) . . . %	18.4	18.5	18.5	18.6	18.6	18.7	18.7
Broken kernels (in weight) . . . %	0.4	0.5	0.6	0.7	0.8	0.8	0.9
Volume-weight (g. / $\frac{1}{4}$ L.)	209.2	210.2	210.2	210.2	211.0	211.2	211.3

The efficiency of this type of removal of moisture was rather inferior to the others in experiments carried out in winter, because the season was already warm, However, the moisture content of rice was decreased from 15.1 per cent to 13.5 per cent with the desiccation of six hours. The number of cracked as well as of broken kernels did not increase at all. The smoothness and the colour of the kernels did not alter, but a little of their lustre was lost. The total volume of rice decreased 2.1 per cent. The general quality was slightly better than that of the preceding experiment. It was found that rice dried by heated air needed a longer period for polishing, and produced broken kernels in less quantity than the formerly undried rice. In comparing rice dried by heated air with undried rice, the taste of the boiled rice was quite similar. In general, the results of the present experiment were satisfactory, and they show that the mixing of chaff with the kernels has a good influence in the desiccation of hulled rice by heated air.

III. Experiments in 1936.

In the experiments conducted in 1935, the influence of heated air upon the quality of hulled rice was determined, and it was found that, when the rice is kept at a temperature of 22—23°C., it can be desiccated and remain in good condition, and that the mixing with it of chaff has a better effect on the drying. In 1936 the authors have conducted seven experiments in replica attempting to confirm the

results in the preceding year. The apparatus employed was the same one used in the previous year. In the present chapter two experiments out of the seven will be described in detail.

Experiment A.

1. Materials and Methods :

Hulled rice with a moisture content of 15.2 per cent was employed, 2.4 *Koku* of rice being mixed with 1.2 *Koku* of chaff, since it was found, in the previous year, that the mixing of chaff gave good results. The temperature of the heated air blown into the chamber was, at the beginning, 33°C., and was lowered gradually to 27°C. during the desiccation, as shown in Table 3. The highest temperature reached by the rice was 24.7°C. at the highest degree. The desiccation was continued for six hours. The rice in the chamber was brought into rotation for 3—4 minutes once every hour. During the rest of the time it remained quiet.

2. Results :

The results are presented in Table 3.

Table 3.

Results of the Desiccation by Heated Air of Hulled Rice Mixed with Chaff.

February 19, 1936, weather clear.

Time	At the beginning	After 1 hour	After 2 hours	After 3 hours	After 4 hours	After 5 hours	After 6 hours
Temperature of the atmosphere · °C.	4.3	6.8	7.9	10.0	0.5	10.2	9.8
Humidity of the atmosphere . . . %	71	59	55	50	49	49	53
Temperature of heated air . . . °C.	30	30	33	32	33	31	27
Temperature of rice °C.	5.5	16.8	22.0	24.0	24.7	23.9	24.0
Moisture content of rice %	15.2	15.0	14.8	14.4	14.0	13.6	13.2
Volume-weight (g. / $\frac{1}{2}$ l.)	213.8	214.2	215.0	214.8	215.3	214.8	215.1
Cracked kernels (in weight) . . . %	34.1	35.0	35.8	35.5	35.3	36.9	38.3
Broken kernels (in weight) . . . %	0.2	0.3	0.4	0.4	0.5	0.4	0.5
Total volume of rice <i>Koku</i>	2.400	—	—	—	—	—	2.363
Examination marks of colour and lustre of the kernels	100	—	—	95	—	—	90

The moisture content of the rice was reduced from 15.2 per cent to 13.2 per cent, i.e., 2 per cent. This shows that the efficiency of desiccation was great. The volume-weight of rice was increased, and the amount of cracked as well as of broken kernels increased a little. The colour and lustre of the kernels remained almost unaltered. The general quality of rice was not damaged at all. The total volume of rice was decreased 1.5 per cent. The above data show, in general, that the desiccation of hulled rice was successful, but that the amount of cracked rice was increased 4.2 per cent, the temperature of the rice at 24.7°C. being too high.

*Experiment B.*1. *Materials and Methods:*

Hulled rice with a moisture content of 15.2 per cent was used. 2.4 *Koku* of the rice was mixed with 1.2 *Koku* of chaff. The temperature of the heated air was 24–35°C. and the highest temperature that the rice reached was 22.9°C. The desiccation was continued for seven hours. The rice was brought into slow rotation for 1–2 minutes every 30 minutes.

2. *Results:*

The results are given in Table 4.

Table 4.

Results of the Desiccation by Heated Air of Hulled Rice Mixed with Chaff.

March 19, 1936, weather clear.

Time	At the beginning	After 1 hour	After 2 hours	After 3 hours	After 4 hours	After 5 hours	After 6 hours	After 7 hours
Temperature of the atmosphere · °C.	5.0	6.0	6.3	7.7	9.2	10.2	10.1	10.2
Humidity of the atmosphere . . . %	60	57	58	56	55	62	55	55
Temperature of heated air . . . °C.	30	35	31	31	26	25	25	24
Temperature of rice °C.	4.5	16.0	22.9	22.8	22.0	22.1	22.3	21.5
Moisture content of rice %	15.2	15.2	14.6	14.1	13.4	13.4	13.2	13.0
Volume-weight (g. / $\frac{1}{4}$ L.)	213.7	214.1	214.5	214.9	215.2	215.7	215.5	215.6
Cracked kernels (in weight) . . . %	19.7	20.9	21.4	21.2	21.9	21.5	22.2	22.0
Broken kernels (in weight) . . . %	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.4
Total volume of rice <i>Koku</i>	2.400	—	—	—	—	—	—	2.364
Examination marks of colour and lustre of the kernels	100	—	—	—	—	—	—	85

The moisture content of rice was decreased 2.2 per cent, and the volume-weight increased a little. The amount of cracked as well as of broken kernels was increased only a little. The colour and lustre of kernels remained nearly unaltered. The results of the desiccation were successful, as was expected. However, the total volume of rice was decreased 1.5 per cent; this is the natural result of desiccation.

IV. Experiments in 1937.

In the experiments in the preceding two years the hulled rice was desiccated by means of the drying machine. The experimental results obtained should be able to be applied to a drying apparatus on a large scale. During the past

15 years, farmers in large numbers in Japan have been provided with drying chambers for desiccating cereals. Generally, the chamber is not large and is heated by "Rentan"-coal. Of course, desiccation in the drying chamber is less efficient than in the drying machine. Moreover, not a great quantity of the products can not be dried at one time. In the authors' opinion, however, the use of a drying chamber is better suited for the farmers' use than the drying machine, since it costs less, is more convenient and can be used for the drying of several kinds of farm products.

In the present experiments the relation of the temperature of the chamber, as well as the rice kernels, and their effects upon the quality of rice was investigated. Eight experiments in replica were conducted. In the following chapters two of the experiments will be described in detail, the others being omitted, since the results are almost similar.

Experiment A.

1. Materials and Methods :

The drying chamber employed in the present experiments is equipped with many shelves along the walls, heaters in the depression in the bottom and ventilators in the roof (Plate II). The dimensions of the chamber are 2.6×2.6×2.3 m., the latter being the height. Hulled rice with a moisture content of 15.5 per cent was used. 1.8 *Koku* of the rice was spread in thin layers on the 18 shelves. The experiment was conducted for a period of 24 hours, namely from 9 a.m. on March 3 to 9 a.m. on March 4, 1937.

2. Results :

The results of the experiment are given in Table 5 and 6.

Table 5.
Temperature and Humidity in the Chamber as well as Temperature
of the Hulled Rice.

Data	Temperature in the chamber	Humidity	Temperature of rice				
			Shelf 1	Shelf 3	Shelf 5	Shelf 7	Shelf 9
At the beginning	6.0	72	5	5	5	5	5
Maximum temperature and minimum humidity during desiccation	34.5	41	33.0	29.5	29.5	29.5	28.5
At the end (after 24 hours)	12.3	52	12.5	12.5	12.5	12.6	11.5

N. B. Nos. of shelves.....from the bottom upwards 1, 2, 3.....9.

It was noticed that the temperature in the chamber as well as of the rice therein reached the maximum temperature in seven or eight hours. The maximum temperature of the chamber was 34.5°C. and the maximum temperature of the rice on shelf No. 5, the middle shelf, was 29.5°C. After 24 hours, the chamber was opened and it was observed that the temperature of the chamber decreased to 12.3°C. and the temperature of rice to 12.5°C.

Table 6.
Quality of Rice After Desiccation.

Data	At the beginning	After the desiccation					
		Shelf 1	Shelf 3	Shelf 5	Shelf 7	Shelf 9	Average
Moisture of rice . . . (%)	15.5	13.5	13.4	13.8	13.7	14.1	13.7
Cracked rice (%)	36.6	40.2	37.3	34.5 (?)	37.9	36.9	38.1*
Volume-weight · (g. / $\frac{1}{4}$ L.)	214.5	216.5	216.4	215.9	215.9	215.7	216.1

* Shelf 5 omitted.

The moisture content of the rice decreased from 15.5 per cent to 13.7 per cent, thus decreasing 1.8 per cent. The amount of cracked kernels increased only 1.5 per cent. The volume-weight of rice increased a little. The total volume of rice decreased 4.1 per cent and the total weight, 2.6 per cent. In general, the results show that the desiccation of rice was conducted under good conditions.

Experiment B.

1. Materials and Methods :

The materials and the methods are the same as in Experiment A. The drying was conducted on February 17 and 18, 1937.

2. Results :

The results are given in Table 7 and 8.

Table 7.
Temperature and Humidity in the Chamber as well as Temperature of the Hulled Rice.

Data	Temperature in the chamber	Humidity	Temperature of rice				
			Shelf 1	Shelf 3	Shelf 5	Shelf 7	Shelf 9
At the beginning	5 °C.	69 %	6.5 °C.	6.5 °C.	6.5 °C.	6.5 °C.	6.5 °C.
Maximum temperature and minimum humidity during desiccation	35.5	38	31.0	30.5	30.5	31.5	30.5
At the end (after 24 hours)	14.0	52	14.0	14.0	14.0	14.0	13.0

After 9 hours the temperature of the chamber reached 35.5°C. and the temperature of rice (on shelf No. 5), 30.5°C., the humidity in the chamber being 38 per cent. As a result of the desiccation, the total weight of rice decreased 2.9 per cent and the total volume, 4.7 per cent. The moisture content decreased from 15.5 per cent to 13 per cent, namely 2.5 per cent. The increase in the number of cracked kernels is relatively slight, namely only 1.9 per cent. The volume-weight increased more or less. The quality of rice was very good. The desiccation experiment was successful.

Table 8.
Quality of Rice After Desiccation.

Data	At the beginning	After the desiccation			
		Shelf 1	Shelf 5	Shelf 9	Average
Moisture content (%)	15.5	12.5	13.1	13.5	13.0
Cracked rice (%)	33.0	35.0	36.1	33.7	34.9
Volume-weight . . . (g. / $\frac{1}{4}$ L.)	215.0	216.9	217.0	216.0	216.6

V. Discussion.

In order to study the removal of moisture from the hulled rice by a heating apparatus, the authors carried out six experiments in 1935, seven experiments in 1936 and eight experiments in 1937 and reached the conclusion that hulled rice can be satisfactorily desiccated with heated air without any distinct damage, if the temperature is not high, the optimum temperature, of course, being different with different desiccating methods and materials. Next, desiccation by heated air shall be discussed further.

1. Removal of the Moisture by a Drying Machine.

The most important problem connected with the desiccation of rice by heated air is the temperature of the air current in the apparatus as well as the temperature of the rice itself. The efficiency of desiccation must be high, but the qualities of rice must not be damaged.

The desiccation of hulled rice occurs only in the case of redrying (secondary drying) of the underdried rice. The moisture content of hulled rice is generally, therefore, not as large as in the case of unhulled rice. The hulled rice employed in the above described experiments had ca. 15–16 per cent of moisture.

After repeated experiments in 1935 and 1936, it was found that, if the dryer "Kanaoka Drying Machine" is employed, *the temperature of the air current blown into the dryer should be 35°C. at the beginning; afterwards it should be decreased to 25°C., with the temperature of the rice 22–23°C.* Using this method, the moisture content of hulled rice with an original moisture content of 15 per cent, will be decreased about 2 per cent, when it is dried for 6–7 hours. If the moisture content is higher than 15 per cent, the rice must be dried for a longer period. At this temperature the germination power is retained in a perfect condition.

In the repeated experiments with the drying machine it was found that, when the hulled rice was mixed with chaff in the proportion of 2:1, the rice was dried more effectively, the friction was less, and the colour and the luster of kernels were good. *It is therefore justifiable to recommend the mixing of chaff with hulled rice, when drying is done by a machine.*

In the case of a drying machine, the cereals rotate continuously in the apparatus. The movement of the grains causes, however, friction of the kernels with the sides of the machine and in consequence the grains become less lustrous. The results are unprofitable. *It is, therefore, advisable to allow the rice kernels to remain undisturbed except for rotating them slowly for periods of 1—2 minutes once every 30 minutes in order to minimize the effect of friction.*

The rice, which was desiccated under the above described conditions, was of very good quality. The amount of cracked kernels increased only a little, the number of broken kernels did not increase at all, the colour remained unaltered and the taste of the polished boiled rice was good. The moisture content of rice was decreased 2 per cent during the process, decreasing from 15 per cent to 13 per cent during the period of drying of 6—7 hours.

2. Removal of Moisture by the Drying Chamber.

In the experiments of 1937, the drying chamber was studied, and after repeated experiments, it was determined that *the permissible maximum temperature of the air in the chamber was 35°C. and the temperature of the rice, 30°C.* The temperature in the chamber was, of course, low at the beginning but gradually rose and after seven hours, it reached the maximum and afterwards decreased. If the temperature rose to 40°C., it was too high. The temperature of rice rose more slowly than the air temperature and it reached the maximum one hour later. When the temperature of rice went over 35°C., it was too high. The efficiency of desiccation by the method of the drying chamber is about 1/3 that by the drying machine, but when the rice is dried 24 hours in the chamber, then the desiccation is more effective than the drying machine employed for a period of 6—7 hours.

The hulled rice desiccated under the above conditions had a good quality. During 24 hours the moisture content of rice was decreased 2.4 per cent, decreasing from 16 per cent to 13.6 per cent. The number of cracked kernels increased only 3 per cent. The volume-weight increased a little, the colour changed slightly, yet was still very good. The germinating power remained in a perfect condition.

In comparing the methods of desiccation by the drying chamber with the drying machine, we find the cost of the former is much smaller than the latter and that the former method is more applicable to the small farmers. The drying machine is more applicable to a landlord, because its desiccation efficiency is large.

3. Application of Drying of Hulled Rice.

In general, the rice must be dried thoroughly before hulling. The removal of moisture from hulled rice is much more difficult than the drying of unhulled rice. The more moisture is removed from rice, the more the quantity of rice is decreased. Moreover, the cost of desiccation is great. Hulled rice with an excessive amount of moisture must, therefore, be consumed before summer. But if the hulled rice must be stored for a long time, it must be redried. In such a case

the methods of drying by heated air can be applied in the removal of the moisture from hulled rice. Generally, the redrying of the rice must be carried out in winter.

IV. Summary.

- 1) In case there is need of storing underdried hulled rice in a great quantities it should be redried by heated air. The authors conducted 21 experiments in 1935—1937 on the suitability of removing moisture from hulled rice by heated air, and attempted to find the most suited process for desiccation.
- 2) By the employment of a drying machine, namely "Kanaoka Drying Machine", it was found that, in order to dry hulled rice having a moisture content of 15–16 per cent, the following conditions are desired:—

Temperature of heated air At the beginning, 35°C., at the end 25°C.

Temperature of rice 22–23°C.

Rotation of rice in the chamber . . . A period of 1–2 minutes once every half to one hour.

Rice mixed with chaff in the proportion of 2 : 1 in volume.

- 3) If the hulled rice is dried under the above mentioned conditions for a period of 6–7 hours, the moisture content decreases 0.3–0.4 per cent per hour and the general quality of the rice is very good. The desiccation is successful.
- 4) In the case of a drying chamber heated with "Rentan"-coal, it was found that hulled rice having a moisture content of 16 per cent had its moisture content decreased 2.4 per cent during a 24-hour period and that the general quality of the rice is very good, if the rice is dried under the following conditions:—

Maximum temperature in the room 35°C.

Maximum temperature in the rice 30°C.

Rice kernels spread on the many shelves in thin layers.

Ventilation and circulation of heated air good.

- 5) In comparing the drying chamber with the drying machine, the efficiency of the former in the removal of moisture is only 1/3 of the latter, but the operation of former costs less, it is more convenient, and is more suited for a small farmer than the latter. In order to dry rice in great quantities, as in the case of a landlord, the drying machine should be employed.

Literature.

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- 2) KONDO, M. and OKAMURA, T., Storage of rice XIII. Storage of rice in tin containers with calcium chloride, with special reference to the underdried product. II. Ber. Ohara Inst., VII: 99-102, 1935.
 - 3) ———, and ISSHIKI, S., Storage of rice XIV. Removal of moisture from the air in a granary and the hulled rice stored therein by a desiccating materials. Ibid., VII: 227-237, 1936.
 - 4) ———, and TERASAKA, Y., Storage of rice XV. Comparison of calcium oxide and calcium chloride as a desiccating material for rice stored in tin containers. Ibid., VII: 329-334, 1936.
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PLATE I.



"Kanaoka Heat Drying Machine" employed in
the Experiments.



Drying Chamber employed in the Experiments.

Interior of the chamber :—

Right and left side walls 9 shelves each.

On the bottom heater of "Rentan"-coal.