Heat as a Means of Controlling Angoumois Grain-Moth. II.*
Velocity of the Rise of Wheat Temperature during Heating.

By

Chukichi Harukawa.

[November 2, 1940]

Introduction.

In two of the previous papers the writer has published the results of the experiments which were carried out in order to determine the efficacy of heating as a means of controlling the Angoumois grain-moth, *Sitotroga cerealella* Oliver.[1),2)]† In those experiments a very small quantity of wheat wrapped in a sheet of cheese-cloth was heated in a constant temperature oven. It was assumed that the temperature of the wheat quickly rose and attained to the air temperature in the oven. However, it may be questioned whether the temperature of the wheat really rose as quickly as the writer had expected, and in later experiments the writer tried to make measurement of wheat temperature during heating.

For artificial drying of grains, it is essential to have the knowledge of the velocity of the rise of grain temperature during heating. It might be expected that much work along this line must have been already carried out. Unfortunately, however, the writer has not been able to find a very reliable result of studies on this subject. Several years ago, the results of some experiments on the artificial drying of rice and wheat were published.[3),4),5)] In those experiments the air temperature in the drying apparatus was usually kept considerably high, and a certain quantity of grains was slowly conveyed through the heated air in the apparatus. Therefore, it may be supposed from them that the grains could be quickly heated; however, in reality, the temperature of the grains was found to be considerably lower than the air temperature.

When rice or wheat is spread in a thin layer on shelves in a drying room as is practised by some farmers, the velocity of rise of grain temperature seems to be affected by various factors; and even after six or seven hours of heating, there

---

* This is a slightly abridged English edition of the writer's paper published in *Nôgaku Kenkyû*, Vol. 25, pp. 180–194, (1935).

† Reference is made by number to "Literature Cited."

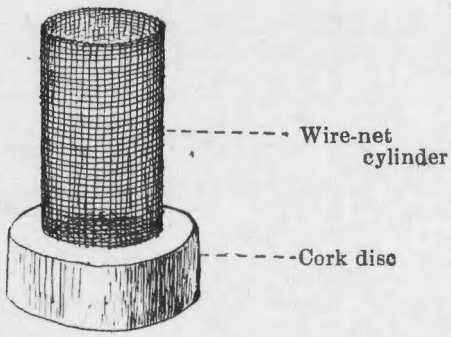
seems to be a considerable difference between the temperature of the oven and that of the grains. In such cases the rate of rise of grain temperature would vary greatly according to various circumstances under which drying is carried out.

The writer has had no intention to undertake a study on artificial drying. He thinks, however, the study on the temperature of grains is indispensable if one attempts to evaluate correctly the efficacy of heat as a means of controlling grain pests. The present experiment conducted by the writer was on a very small scale and though the results can not yet be considered conclusive, he desires to report on them since he thinks some interesting data have been obtained.

Method and Plan of Experiment.

The material used for the experiment was wheat. A small cylinder made of wire-netting was fixed on a cork disc which was some 2.5 cm. thick (Fig. 1). This wire-net cylinder was of two sizes, the one being 3 cm. in diameter and the other about 6 cm. in diameter. The length was about 6 cm. in either case.

Fig. 1.



A small quantity of wheat was put in this wire-net cylinder and was placed in an constant temperature oven. For measuring temperature of wheat, a thermocouple combined with a Leeds-Northrup galvanometer was used. Although the sensitivity of this galvanometer was not very high, the accuracy of temperature measurement was approximately $\pm 0.5°C$. Temperature of wheat was measured usually either at a depth of 1.5 cm. or at 3 cm. below the surface. In a few cases it was measured at a depth of 3.5 cm.

In the present experiment chief factors which seemed to have affected the rise of wheat temperature were the moisture content of the wheat and the difference of temperature between the wheat and the air in the oven. Strictly speaking, the temperature of wheat at the beginning of each experiment differed slightly according to the time when experiments were conducted, but the majority of the experiments were carried out during July and August so that the temperature difference must have been very small. Besides, the quantity of wheat used in each test was very small, and its temperature rose rapidly at the beginning of each test. In consideration of these circumstances, it has been assumed that the initial temperature of wheat had little effect on the duration of heating required.

For convenience of description, the difference between the temperature to which wheat should be heated and that of the electric oven is termed "temperature gradient." In regard to the moisture content, three kinds of wheat samples

were prepared: namely, wheat containing moisture at the rate of approximately 11, 13 and 15 % respectively.

Results of Experiment.

The temperature of wheat was determined several times during heating at certain intervals, and the time required to heat the wheat to the prescribed temperature was also determined in each test. The results of experiment are shown in tables I to IV, of which tables III and IV contain the results of observations on the rise of wheat temperature in several tests in the experiment.

Table I.

Prescribed Temperature to which Wheat was raised, Moisture Content of Wheat and Duration required for Heating.

Moisture Content of Wheat	Prescribed Temperature	Average Duration required for Heating	Remarks
11.2 – 11.4	50	21.0	Temperature gradient 10°C.
„	60	43.5	Quantity of wheat 20 c.c.
„	70	52.5	Diameter of wire-net cylinder 3 cm.
„	80	69.5	Height of wheat column in wire-net 3 cm.
13.4 – 13.5	50	21.5	
„	60	50.5	Tip of thermocouple 1.5 cm. below the surface of wheat.
„	70	69.6	
„	80	83.5	
15.0 – 15.7	50	25.5	
„	60	63.5	
„	70	80.6	
„	80	85.5	

Table II.

Effect of Quantity of Wheat on the Duration of Heating.

Test No.	Prescribed Temperature	Diameter × Height of Wire-Netting (cm.)	Duration of Heating required (minutes)	Moisture Content of Wheat	Tip of Thermocouple (cm.) below the Surface of Wheat
No. 1	60	3 × 1.8	20.0	11.2	1.5
„ 2	„	3 × 3	26.6	„	„
„ 3	„	6 × 1.8	39.0	„	„
„ 4	„	6 × 3	48.5	„	„
„ 5	„	6 × 6	85.0	„	3.0
„ 6	70	3 × 3	27.5	11.2 – 11.4	1.5
„ 7	„	6 × 1.8	57.5	„	„
„ 8	80	3 × 3	51.0	11.3 – 11.4	„

Remark: Temperature gradient was always 15°C.

Table III.

Moisture Content of Wheat and Rise of Wheat Temperature.

(A) Prescribed Temperature . . . 60°C.

Test No. 26		Test No. 38		Test No. 49	
Moisture Content of Wheat 11.4%		Moisture Content of Wheat 13.4%		Moisture Content of Wheat 15.1%	
Time of Observation	Temperature of Wheat	Time of Observation	Temperature of Wheat	Time of Observation	Temperature of Wheat
8:43	(30.0)	11:10	(30.0)	8:38	(30.0)
„ 45	39.5	„ 12	39.5	„ 40	41.3
„ 50	44.6	„ 15	44.3	„ 50	51.8
9:00	55.4	„ 20	50.3	9:00	—
„ 10	58.1	„ 30	55.0	„ 10	57.2
„ 15	59.0	„ 40	57.9	„ 40	59.6
„ 20	59.8	„ 45	59.7	„ 44	60.2
„ 23	60.0	12:00	60.0	—	—

(B) Prescribed Temperature . . . 80°C.

Test No. 29		Test No. 44		Test No. 45	
Moisture Content of Wheat 11.4%		Moisture Content of Wheat 13.4%		Moisture Content of Wheat 15.0%	
Time of Observation	Temperature of Wheat	Time of Observation	Temperature of Wheat	Time of Observation	Temperature of Wheat
3:32	(30.0)	8:20	(30.0)	9:47	(30.0)
„ 35	46.6	„ 22	47.6	„ 50	46.9
„ 40	57.2	„ 25	54.3	10:00	60.0
„ 50	66.7	„ 35	67.8	„ 20	69.8
4:00	71.3	„ 45	71.1	11:00	75.7
„ 20	76.8	9:10	73.2	„ 10	78.4
„ 35	79.1	„ 35	78.5	„ 13	79.6
„ 39	80.0	„ 42	80.0	„ 15	80.0

Remarks: Diameter of wheat column in wire-netting 3 cm., the height of the column 3 cm.
Temperature gradient 10°C.

From the data shown in the tables I to IV, the following deduction can be made. The data given in table I show in what manner the prescribed temperature to which wheat should attain affects the time required for heating the wheat. In these tests the temperature gradient was 10°C. The quantity of wheat used was approximately 20 c.c. which is a very small volume when it is compared with the capacity of the oven. The tip of the thermocouple was at a depth of 1.5 cm. below the upper surface and also 1.5 cm. from the lateral surface of wheat column in the wire-netting. Since the moisture contained in the wheat evaporates gradu-

Table IV.

Quantity of Wheat and Rise of Wheat Temperature.

Test No. 10		Test No. 7		Test No. 20	
Diameter of Wire-Netting 3 cm. Height of Wheat Column 3 cm. Moisture Content 11.2%		Diameter of Wire-Netting 6 cm. Height of Wheat Column 3 cm. Moisture Content 11.2%		Diameter of Wire-Netting 6 cm. Height of Wheat Column 6 cm. Moisture Content 11.4%	
Time of Observation	Temperature of Wheat	Time of Observation	Temperature of Wheat	Time of Observation	Temperature of Wheat
10 : 20	(30.0)	4 : 20	(30.0)	9 : 25	(30.0)
„ 25	43.6	„ 25	41.1	„ 30	32.2
„ 30	50.4	„ 30	44.1	„ 40	38.1
„ 35	55.9	„ 35	49.0	„ 50	44.7
„ 40	58.6	„ 40	53.4	10 : 00	48.8
„ 45	59.6	„ 45	56.3	„ 10	53.8
„ 50	61.4	„ 50	58.5	„ 20	56.3
		5 : 00	59.4	„ 30	58.0
		„ 05	60.1	„ 40	58.8
				„ 50	60.1

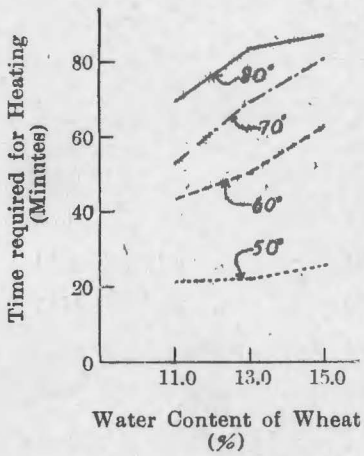
Remarks: Prescribed temperature . . . 60°C.
Temperature gradient . . . . 15°C.
Tip of thermocouple was situated at the center of wheat in wire-netting.

ally when the wheat is heated, the latent heat for evaporation tends to cool the wheat. The rate of evaporation differs according to the temperature in the oven and also to the moisture content of wheat.

The duration of heating necessary for the required temperature increased as the temperature to be attained was higher as is apparent from the data in table I, but the rate of the increase in this duration of heating varied with the moisture content of wheat. Thus, heating for 21 minutes was sufficient to heat wheat to 50°C. when the moisture content was 11.2 – 11.4%, while approximately 70 minutes were required to heat the wheat of the same water content to 80°C. When the water content of wheat was 13.4 – 13.5%, 21.5 minutes were required in an average to reach 50°C., while 25.5 minutes were necessary to attain to the same temperature when the moisture content was 15.0 – 15.7%. Thus, the duration of heating must be longer as the water content of the wheat is greater; but, when the temperature to be reached was 50°C., only a slight increase in duration of heating was sufficient. However, when the prescribed temperature to which wheat should attain was 60°C. or higher, the time required for heating must be increased markedly with the increase in the moisture content of wheat. And the rate of

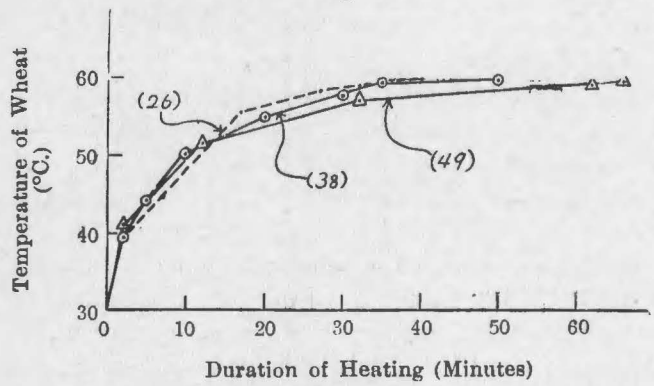
this increase in the necessary duration of heating becomes greater with the rise of temperature to which wheat should reach. This tendency is clearly shown in figure 2 by the inclination of the curves which represent the relation of the moisture content of wheat to the necessary duration of heating. When the temperature to be reached was 80°C., the rate of increase in the duration of heating became apparently somewhat smaller. The reason for this is probably as follows: since the quantity of wheat used for each test is very small, the water contained in the wheat rapidly decreases by evaporation before the temperature of wheat attains to 80°C. Thus, the cooling effect due to evaporation of water becomes rapidly smaller and disappears in a short time.

Fig. 2.



The rise of wheat temperature during heating. The data in table III, (A) show the rise of wheat temperature in a test in which the height of the wheat column in the wire-netting was about 3 cm., its diameter being also about 3 cm., the temperature to be attained was 60°C. and the temperature gradient was 10°C. This result is shown as a graph in figure 3. As is apparent from table III and figure 3, the temperature of wheat at first rose very rapidly, but the velocity of rising became gradually smaller and near the close of each test the temperature of wheat changed very little. The rapid rise at the outset of heating is obviously due to a great difference of temperature between the wheat

Fig. 3.



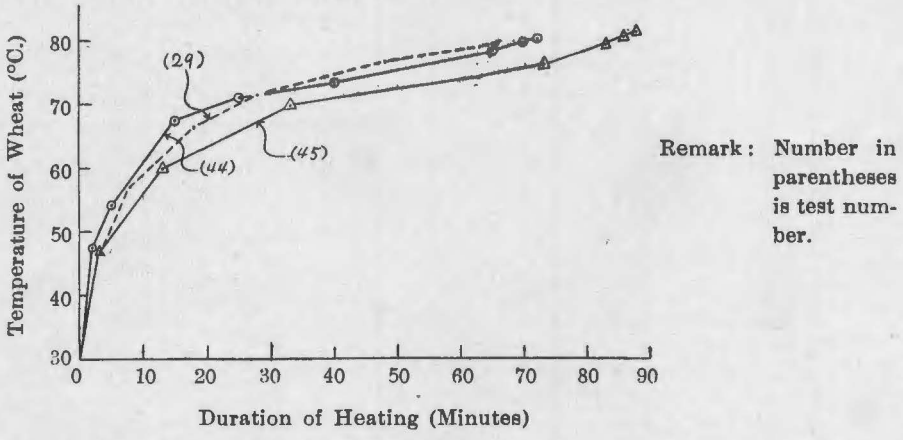
Remark: Number in parentheses is test number.

and the oven, and the very small rate of rise near the close of each test is partly due to the decrease of the temperature difference, but another cause is the cooling effect due to the evaporation of moisture contained by the wheat. As is apparent from figure 3, the speed of rise of wheat temperature was very nearly equal at first

for wheat samples of different moisture contents. However, after a certain high temperature was attained, the temperature of wheat with larger moisture content was always lower than that of the wheat with smaller moisture content. As a consequence, the former needed longer time in attaining to the same temperature than the latter.

The data in table III, (B) are the results of observations in a similar experiment in which the temperature to be reached was 80°C. and the temperature of the oven was 90°C. These results are shown in figure 4 graphically. Figure 4 shows that the manner of the rise of temperature of wheat was essentially the same as in figure 3. The only difference is that it took longer time for wheat to reach the prescribed temperature in the tests which are shown in figure 4.

Fig. 4.

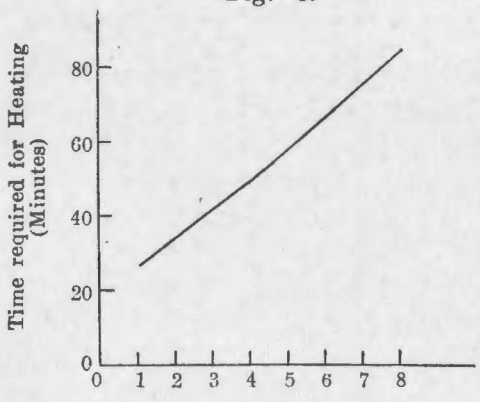


Effect of the quantity of wheat on the rise of temperature. The data in table II show the duration of heating which was required for wheat to reach to the prescribed temperature when different quantities of wheat were used. The moisture contents of wheat samples used in different tests were the same at the outset of heating, and the temperature gradient was 15°C. in all the tests. In these tests the diameter of wheat column in wire-netting was of two kinds: namely, 3 and 6 centimers, and the height of the column varied with the quantity of wheat used.

From the data in table II, the following deductions may be made. As might be expected, the time required for heating becomes longer as the quantity of wheat used becomes larger. Since in tests 1 and 3 the height of wheat column was only 1.8 cm. and the tip of thermocouple was only 3 mm. above the cork disc, these two tests will be excluded from consideration. In tests 2, 4 and 5 the prescribed temperature to which wheat should reach was 60°C., the thickness of wheat layer was at least 3 cm. and the tip of thermocouple was situated at least 1.5 cm. above the bottom of wheat layer. The ratio of the quantity of wheat in these three tests was 1:4:8. Now, taking this ratio on the abscissa and the

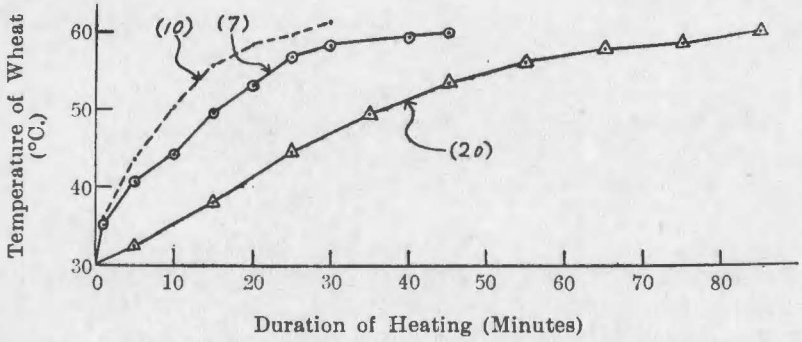
duration of heating on the ordinates, we obtain figure 5. This figure indicates that the three points representing the time required for heating lie almost on a straight line, which shows that the time of heating is proportional to the quantity of wheat.

Fig. 5.



The data in table IV show how the rise of wheat temperature is affected by the quantity of wheat. By plotting these data we obtain the curves shown in figure 6, which represent the relation of wheat temperature to the duration of heating. According to figure 6, in test No. 10 in which diameter of wheat column and height are both 3 cm. the rise of wheat temperature is very rapid in the beginning and the velocity of rise is greater than the rate of increase in the duration of heating. As a result the curve b comes concave on the lower side.

Fig. 6.



Remark: Number in parentheses is test number.

In test No. 20 where the diameter of wheat column and its height are both 6 cm., the rise of wheat temperature is at first gradual and almost proportional to the increase of dufation of heating. As a result the curve showing the relation of wheat temperature to the duration of heating becomes almost a straight line for the former half of the duration of heating.

Summary and Conclusion.

Rise of temperature of a small quantity of wheat placed in a small wire-net cylinder and heated in a constant temperature oven was studied. Under such

conditions the moisture contained in wheat evaporates when the temperature of wheat rises and tends to slow down the speed of the rise of wheat temperature.

The velocity of rise of wheat temperature is affected by the quantity of wheat, the moisture content of wheat and the difference between the temperature to which wheat is required to reach and that of the oven.

When the cylinder of wire-netting 3 cm. in diameter was filled with wheat of 11% moisture content to a depth of 3 cm. and the difference between the temperature of the oven and that to which wheat should reach was 10°, it took about 21 minutes for the wheat to reach 50°C., and about 44 minutes to reach 60°C.

When the prescribed temperature to be attained by wheat was 50°C., the increase of moisture content of wheat from 11% to 15% did not much affect the time required for heating. But, when we want to heat wheat up to 60°C., the increase in moisture content markedly prolonged the duration of heating. The velocity of rise of wheat temperature was not much affected by moisture content for a short while after the outset of heating, but, after a temperature of about 50°C. was reached, the rise of wheat temperature became much slower in the wheat with greater amount of moisture than in the wheat with smaller moisture content.

The quantity of wheat markedly affects the rise of wheat temperature. In the writer's experiment, it took about 20 minutes to heat the wheat with 11% moisture content up to 60°C. when the quantity (volume of wheat in wire-netting in this case) of wheat was 3 cm. in diameter by 3 cm. in height and the temperature gradient was 15°C., while it took about 85 minutes when the volume of wheat was 6 cm. in diameter and also 6 cm. in height.

The duration of heating necessary to raise the temperature of wheat to a certain desired temperature seemed to be proportional to the quantity of wheat so far as the quantity of wheat is such a small amount as used in the writer's experiment.

Since the purpose of the present experiment was primarily to obtained data which could be compared with the results of the experiment which the writer had conducted previously to kill the Angoumois grain-moth infesting wheat, the experiment was conducted on a very small scale. Therefore, the present experiment can not be directly compared with the artificial drying of grains on a practical scale.

Literature Cited.

(1) Harukawa, C. and Kumashiro, S., Heat as a means of controlling the Angoumois grain-moth. (I) Berichte d. Ōhara Inst. f. landw. Forsch., Kurashiki, Bd. VI, Heft 3, S. 393–406, 1934.

(2) Harukawa, C. (春川忠吉), 加熱によつて麥蛾を驅除すること可能なりや. 農業及園藝, 第9卷, 451–459頁, 昭和9年.

(3) Gifu Agricultural Experiment Station (岐阜縣立農事試驗場), 昭和7年度業務功程, 138–145頁, 昭和8年.

(4) Okayama Agricultural Experiment Station (岡山縣立農事試驗場), 試驗成績, 第55報, 昭和10年.
(5) Shimane Agricultural Experiment Station (島根縣立農事試驗場), 彙報, 第232號, 1-8頁, 昭和4年.