

A STUDY OF THE OXYGEN RESPIRATION IN CORN AND WHEAT KERNELS  
AS MEASURED BY THE WARBURG MANOMETER TECHNIQUE

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## INTRODUCTION

The study of the relation of the water content in cereals to their respiration and storage has been studied rather extensively but this work has been confined mainly to the water imbibed by mature grain. The chief purpose of the investigation reported in this paper was to study the effect on respiration of the changing percentage of natural water in wheat and corn during the ripening and maturing period, and during storage under different conditions.

In previous work on imbibed water and respiratory intensity the respiration of the grain at any given moisture content was determined at some one time after the moisture content had been raised. It was assumed that the time rate of respiration would be constant. In this investigation emphasis was placed on the time rate of respiration for each different percentage of moisture. It is very likely that the changing ratio of free and bound water in cereals will prove very important in solving some of the perplexing problems concerning water relations in cereals. This phase of the general problem is to be investigated.

Most of the investigations on the respiration in cereals have been carried out by research methods of a macro nature in which the carbon dioxide evolved was measured. With the introduction of manometric methods, such as that involving the use of the Warburg manometer and a constant volume type of respirometer, one may very conveniently and accurately study the oxygen respiration of small quantities of material for long or short periods. The first part of the present investigation was concerned with the adaptation of this manometric technique to the type of plant

material used in this study.

Because of the rapid changes in the relative percentages of the different carbohydrates in corn during ripening and under different storage conditions, considerable experimental data on the correlation of different sugars to respiratory intensity of corn are included in this paper.

## REVIEW OF LITERATURE

As early as 1901 Kolkwitz (12) found that barley kernels with 10 to 11 percent moisture liberated only .35 mgm carbon dioxide per kilo per hour, while kernels with 19 to 20 percent liberated 3.69 mgm. After the moisture content was 33 percent 2000 mgm of the gas was given off. Bailey (4) in 1921 showed that corn with 15 to 16 percent moisture respired about 5 times greater than grain with 12 to 13 percent moisture. Bailey and Gurjar (5) observed that wheat at 17.1 percent moisture respired about 20 times greater than wheat with 12.5 percent moisture. The same investigators observed the same effect of moisture on the respiration in rice.

Bakke and Noecker (7) have applied manometric methods to a study of the oxygen consumption as effected by the moisture content in oat seeds. The same general relation was found in that the respiration increased markedly between 16 to 17 percent moisture.

Gerber (10) in 1900 made a comparative study of the oleaginous seeds during their development. The volumes of oxygen consumed and carbon dioxide evolved were measured. Linum seeds were studied from the time the grains were light green on June 15 until they were brown on June 27. The volume of oxygen decreased from 897 cmm on June 15 to 101 cmm on June 27. The R. Q. also fell from 1.31 at the beginning to 0.64 on June 27. Green castor beans were studied from the time a single fruit weighed 0.10 grams till the weight increased to 3.15 grams. The oxygen consumed was highest when the fruit weighed 2.15 grams, and the lowest when the browned fruit weighed 1.20 grams. With the development of the fruit the R. Q. increased from 0.81 to 1.18 and with browning and loss of water fell to 0.41. Rape seeds

were also studied and were found to give results similar to those reported for the castor bean.

McGinnus and Taylor (13) in 1923 studied the effect of respiration upon the protein percentage of wheat, oats, and barley. Kernels of the grain were analyzed and tested when they still contained 40 percent moisture. The respiration changes were studied at 30°C. by collecting the carbon dioxide evolved. The respiration rate of wheat fell gradually from 120 mgm carbon dioxide per 100 grams dry weight per hour at 46 percent moisture, 55 mgm at 33 percent, to 16 mgm at 12.7 percent moisture. The lowest rate of respiration of 7.9 mgm was observed when the grain contained 15.1 percent moisture. It was concluded that the protein composition was influenced to a marked degree by the loss of carbohydrate material during ripening but factors other than respiration or those in connection with the process contribute largely to the formation of high protein grains.

Appleman and Arthur (2) stored green Stowell's Evergreen corn at 0°, 10°, 20°, and 30°C. and studied the carbohydrate changes. The percentages of total sugars lost in 24 hours at the respective temperatures were 7, 16, 25, and 50 percent. By the end of 4 days storage at 20° and 30° the concentration of sugars became constant, the higher temperature hastening the time for equilibrium to be reached. Appleman (3) also showed that respiration in sweet corn as measured by the evolution of carbon dioxide, is very high when the corn is first pulled but it falls off rapidly with storage.



ADAPTATION AND USE OF THE WARBURG MANOMETER AND A  
SPECIAL RESPIROMETER FOR THE RESPIRATION MEASUREMENTS

Description of apparatus.---The Warburg manometer attached to a special constant volume type of respirometer is shown in figure 1. The respiring system gives off carbon dioxide and consumes oxygen during the oxidation-reduction reaction. In the respirometer used in this study a receptacle is provided in which 4 cc of a 15 percent potassium hydroxide solution is placed to absorb the carbon dioxide given off. With the respiring material in a closed system and the carbon dioxide being continuously absorbed, the net result is a decrease of pressure in the system due to the removal of some of the oxygen. This decrease in pressure is measured by the Warburg manometer. When the decrease in pressure is known, it is possible to calculate the amount of oxygen consumed.

The Warburg manometer consists of a U-shaped tube of fairly uniform bore about 0.9 sq. mm. in cross-sectional area. The tubes are mounted on a wooden frame the lower end of which bears a brass slide, by means of which the whole may be fastened to a thermostat. The vertical sides of the tubes are graduated in millimeters for a distance of 30 cm. A suitable white background is mounted behind the tubes to facilitate reading the level of the liquid. At the bottom of the U-shaped tubes there is an outlet to which a rubber tube closed at one end is attached. By placing an adjustable screw clamp on this tubing it is possible to raise or lower the liquid in the manometer to any position desired.

The liquid used is a Brodie's solution the composition of which is as follows:

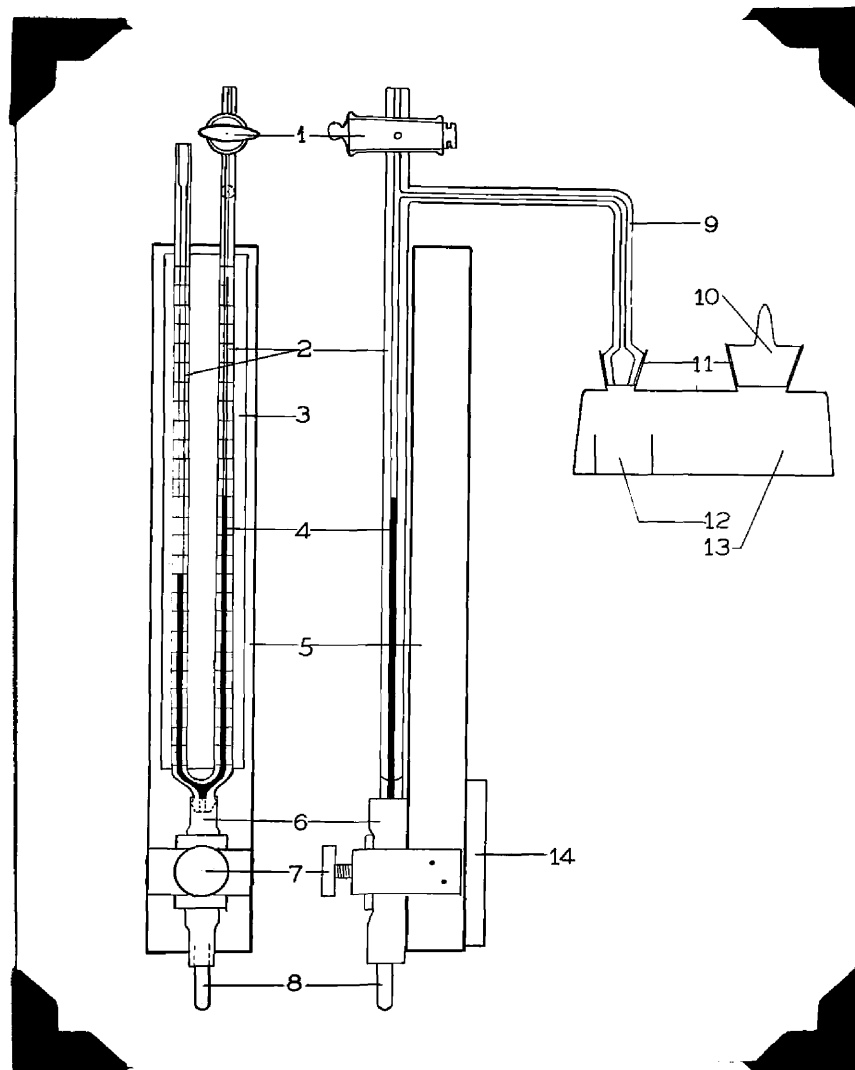


Figure 1. Warburg Manometer

- |   |  |
|---|--|
| 1. Stopcock.  | 7. Adjustable screw clamp.                         |
| 2. U tube of Warburg manometer with a calibrated scale etched on the tubes. | 8. Glass reservoir.                                |
| 3. A white cardboard background.  | 9. Connecting tube.                                |
| 4. Manometer liquid (Brodie solution).                                      | 10. Glass stopper.                                 |
| 5. Wooden frame.  | 11. Ground glass joints.                           |
| 6. Rubber reservoir.  | 12. Receptacle for alkali.                         |
|   | 13. Experimental vessel.                           |
|   | 14. Brass frame to attach manometer to thermostat. |

500 ccs water  
23 g sodium chloride  
5 g sodium choleate  
A few drops of an alcoholic thymol solution

One end of the manometer is open to the air; the other end carries a tube which ends in a standard taper to fit the opening in the respirometer. The respirometers used in this study are rather large in comparison to the type usually used in respiration studies. The size obviously allows the use of larger samples of tissue. The volume of the respirometers varies from 82.75 to 98.01 cc. They vary in external dimensions but average 9 cm in length, 4 cm in width, and 2.5 cm in depth. The diameter of the opening through which the tissue passes is 2.5 cm. They were designed by Dr. C. O. Appleman.

The tube leading to the respirometer bears a side tube which has a stopcock inserted. This is used to release the negative pressure built up by the continuous removal of oxygen by the respiring material. Turning the stopcock to the open position allows air to enter and again equalize the pressures on the two columns of liquid.

Calibration of the apparatus.—The calibration of the apparatus consisted mainly of two steps; the first, finding the volume of the gas space in the closed system, and second, determining the density of the Brodie's solution.

The volume of the gas space was determined by two different methods. In the first procedure the volume was measured by determining the weight of mercury occupied by the space. In the second method a chemical reaction was carried out in the respirometer with the liberation of a known amount of gas.

The experimental vessel was first attached to the manometer and filled with clean mercury. The ground glass stopper was then inserted, which forced the mercury up the connecting tube to some level that was marked. The vessel was then detached and the mercury weighed. Secondly, with the stopcock (1 in fig. 1) closed, the manometer was inverted and filled with mercury so that the level stood at the line marked on the connecting tube; the other level of mercury was then read on the calibrated scale. This mercury was then poured out and weighed.

The third step in this method of calibration consisted in obtaining the volume from the point read on the calibrated scale down to the 150.0 mm mark. This mark was arbitrarily chosen as the reference point; any other might have been chosen. This volume was obtained by getting the cross-sectional area of the bore. This was done by placing the manometer in the normal position and then filling with mercury, with the screw clamp at the bottom closed. Enough mercury was added so that the level in both limbs stood at the 300.0 mm mark. The screw clamp was then opened and some of the liquid allowed to run into a previously tared weighing bottle. Another reading of the mercury levels was taken. The cross-sectional area of bore was then easily calculated. This data also showed at the same time the uniformity of the bore. Knowing the cross-sectional area per centimeter length of tube made it possible to calculate the volume from the original reading down to the 150.0 mm mark.

With these three values the volume of the gas space was calculated knowing the density of mercury at the temperature in the laboratory. Triplicate determinations were made with each of the six manometers and their corresponding respirometers.

The second method of calibrating the apparatus was the simpler and probably the more accurate. A known amount of carbon dioxide was liberated from the action of a 10 percent sulphuric acid solution on an accurately weighed amount of sodium bicarbonate, usually 15 to 20 mg. Because of the great increase in pressure at the time the gas was liberated mercury was substituted for the Brodie's solution in the manometers. After all the carbon dioxide was liberated the manometers were read by adjusting the mercury level in the column attached to the respirometer to the 150.0 mm mark and reading the level in the left hand column. (open limb of the manometer.) By substituting the value  $h$ , which is the height of the mercury column above the 150.0 mm mark in the open limb, and  $x$ , the amount of gas produced,  $V_g$ , the volume of the gas space may be calculated using the equation:

$$X = h \left( \frac{V_g x \frac{273}{T}}{P_0} \right)$$

To insure that the theoretically calculated amount of carbon dioxide was being produced, a series of reactions was made to take place in the respirometers with 4 cc of 15 percent potassium hydroxide solution in the receptacles provided. It was found that absorption of carbon dioxide by the alkali solution as noted by the first noticeable decrease in pressure started about 50 to 60 seconds after the reaction had been started. The vessels were left in the thermostat 24 hours before the alkali was titrated. Triplicate titrations were made; 1 cc of solution was used for each titration. A few crystals of barium chloride were added to the alkali to fix the carbon dioxide present as barium carbonate. The excess alkali was neutralized, with phenolphthalein as an indicator. Then 8 drops

of an 0.01 percent methyl orange solution were added and the titration continued till the usual pink color was obtained. Hydrochloric acid of 0.0735 normality was used for the latter titration. The average titrated values varied about 2.0 percent from the calculated values of the milligrams of carbon dioxide. Four determinations of the volume of gas space by the liberation of carbon dioxide were made.

Variations in the determinations of the gas space volume by weighing of mercury method and the gas liberation method were no greater than 2.5 percent. The average value of the determinations was taken as the  $V_g$  in the formula given below.

The density of the Brodie's solution was determined by the picnometer method. Duplicate determinations were made. The average density at 25° C was 1.028 g. per cc.

Absorption of carbon dioxide.--It has been shown by Dixon and Elliott (9) that considerable error in the first readings may be introduced when measuring the oxygen consumption of a system by manometric methods if sufficient time is not allowed for the equilibrium rate of absorption of carbon dioxide by the alkali solution to be reached. If the taps are closed before a steady rate of absorption has been reached, the manometer readings will be too low. Therefore it was necessary to determine experimentally the time required for equilibrium to be reached.

From 2 to 3 mg of sodium bicarbonate were placed in one corner of the respirometer, and 0.2 cc of a 10 percent sulfuric acid solution in a corner opposite the salt. The receptacle was provided with 4 cc of the 15 percent alkali solution. The respirometer to which the manometer was attached was immersed in a constant temperature water bath for one hour. At the end of this time the respirometer was tilted to bring the acid in contact with the bicarbonate. The amount of carbon dioxide present at

varying times after the start of reaction was calculated. The rate of absorption of the carbon dioxide by the alkali solution is shown in figure 2.

The formula given by Dixon and Elliott was applied to calculate the time when 99 percent of the amount of gas present at infinite time was in the respirometer.

$$(1) x = \frac{r}{c} (1 - e^{-ct})$$

where  $x$  = volume of carbon dioxide (cmm) in gas phase of respirometer at any instant,

$r$  = rate of evolution of carbon dioxide in cubic millimeters per minute,

$c$  = constant depending on respirometer,

$t$  = time in minutes.

At 99 percent equilibrium,  $x = 99 x_{\infty}$  ;

where  $x_{\infty}$  from (1) above is  $\frac{r}{c}$ .

$$t_{99\%} = \frac{4.6}{c}$$

The rate of absorption is equal to  $cx$  or to the tangent of the absorption rate curve.

$$c = \frac{\text{value of tangent}}{x \text{ (amount of gas present at point of tangency)}}$$

The values of the necessary data have been calculated and the  $t_{99\%}$  determined. The data are given in table 1.

From the calculated values of  $t_{99\%}$  it is seen that 30 to 35 minutes should be sufficient time to allow for an equilibrium to be reached in the respirometers.

Table 1.--The time required for 99 percent equilibrium of the absorption of CO<sub>2</sub> to be attained, and other data necessary for the calculation.

Respirometer number	Time after start of reaction	Carbon dioxide present	Tangent	Value of c.10 <sup>-2</sup>	t <sub>99%</sub> min
	min	cmm			min
2	4	441.5	70	15.9	29
	9	190.7	37	19.4	23.7
	13	97.2	18.3	18.8	24.4
	3	291.1	42.5	14.6	31.5
3	8	131.3	20.0	15.2	30.2
	11	86.8	14.1	16.2	28.3
4	4	511.5	73.0	14.3	32.2
	10	205.7	35.0	17.0	27.0
	15	107.1	17.2	16.0	28.6
6	2	320.0	62.5	19.5	23.5
	6	155.7	27.5	17.6	26.0
	10	78.9	15.5	19.7	23.4



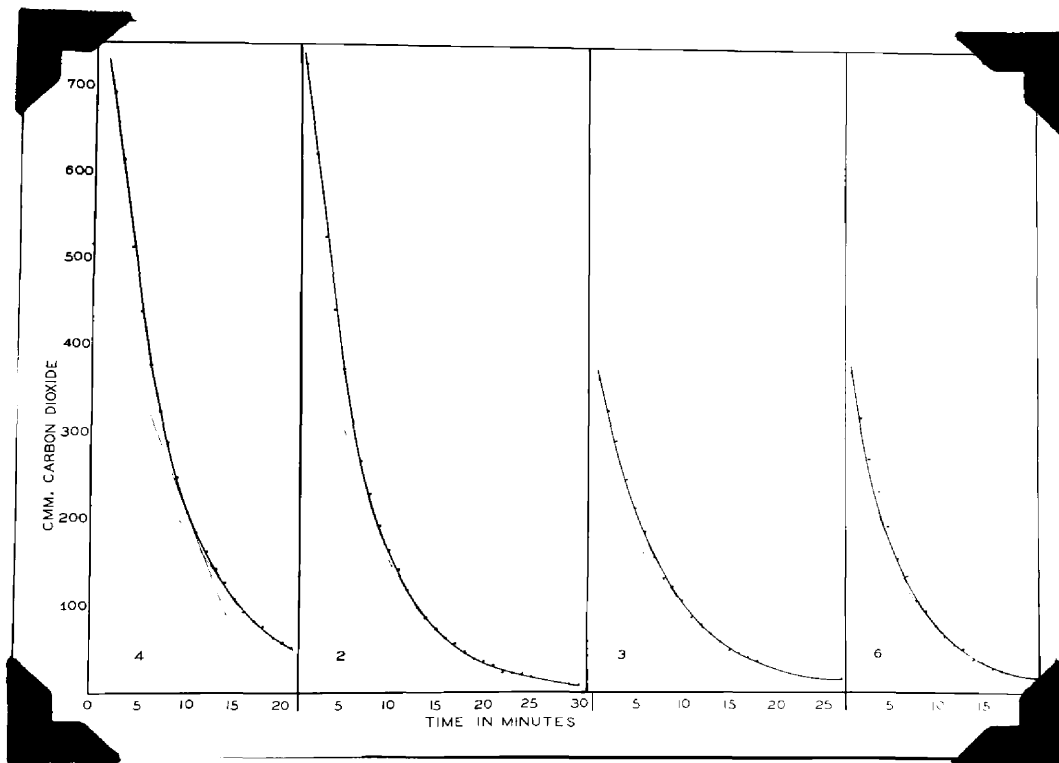


Fig. 2. The rate of carbon dioxide absorption by the alkali solution when placed in the respirometers. The number of the respirometer appears in the lower left corner of each curve.

Derivation of formula for calculating oxygen absorbed.—When oxygen measurements are being made a negative pressure results in the respirometer; this is shown by the difference of levels in the manometer (see fig. 1). The reading of the apparatus is obtained by subtracting the reading in the open limb when the right column is at 150 mm from 150.0. Still another reading must be made at the same time the experimental manometer is read. A thermobarometer, which is a manometer with a vessel containing a little water, is read. The thermobarometer reading takes care of any temperature and barometric changes that may have occurred since the last reading. The corrected level of the Brodie's solution below the 150.0 mm mark is the  $h$  in the equation.

For convenience, all volumes are expressed in cubic millimeters, all readings in millimeters, and all pressures in millimeters.

$V_g$  = volume of gas space.

$T$  = absolute temperature of the water bath.

$P$  = initial pressure in the vessel (in general equal to the barometric pressure).

$P_0$  = the normal pressure (760 mm of Hg in mm of manometer fluid).

$p$  = vapor pressure of water at temperature  $T$ .

Then the initial amount of gas at standard conditions in the gas space is:

$$V_g \times \frac{273}{T} \times \frac{P-p}{P_0}$$

The final amount of gas in the gas space is:

$$V_g \times \frac{273}{T} \times \frac{P - p + h}{P_0}$$

Now obviously the amount of gas absorbed,  $x$ , is equal to the difference of the gas initially present and the final amount of gas.

$$X = \left( V_g \times \frac{273}{T} \times \frac{P - p + h}{P_o} \right) - \left( V_g \times \frac{273}{T} \times \frac{P - p}{P_o} \right)$$

$$(1) X = h \left( \frac{V_g \times \frac{273}{T}}{P_o} \right)$$

It must be remembered that no account of signs was made in the derivation. When measuring oxygen absorption  $h$  will be negative (negative pressure), so that  $X$  is equal to a negative quantity indicating that the gas is consumed.

The quantity in brackets is a constant for any given manometer and respirometer at a given temperature. This quantity is then known as the constant,  $K$ , of the set. It is obvious that each sample of tissue placed in the vessel requires the calculation of a new constant. The value of  $V_g$  for any particular experiment is then the combined volume of the tissue and the alkali subtracted from the volume of the gas space. Substituting this new value of  $V_g$  in the equation simply reduces it to

$$(2) X = hK_2$$

$K_2$  is the constant when the corrected  $V_g$  is used.  $P_o$  in equation (1) is easily calculated by the following formula:

$$P_o = 760.0 \times \frac{13.54}{D}$$

where  $D$  is the density of the Brodie's solution. (1.028 at 25°C)

A mercury thermoregulator was used which held the temperature of the water bath at 25°C ± .02°.

The apparatus was originally designed to measure the oxygen absorbed by pieces of tissue immersed in a solution. In this study the shaking apparatus was not used since the tissue was placed in the vessel in the absence of a liquid.

Effect on Respiration of Decreased Oxygen Tension  
in the Constant Volume Respirometer

The effect of the oxygen tension on the respiration of the plant tissue will depend on the type of tissue and the condition when it is studied. Miller (15) very generally says that the respiration intensity is not markedly changed when the oxygen supply is reduced to one-half that normally present in the air. According to Stich (19) the oxygen absorption is largely independent of the oxygen tension of the environment until the content in the air is reduced to 5 to 8 percent. The production of carbon dioxide is weakened only when the oxygen content is reduced to 2 percent. These values, of course, vary with different tissues. The R.Q. for the seedlings of wheat and corn becomes superior to unity at 3 percent oxygen; for oats at 5.5 percent; and for bulbs of narcissus at 10.5 percent oxygen. The respiratory quotient was 1.04; at 7.5 percent oxygen, it was 2.37.

Chevillard, Hamon, Meyer, and Plantefol have studied the respiration-oxygen tension curves of fragments of potato tissue, turnip, mushroom, and leaves of cress. The production of carbon dioxide from potato tissue was not influenced until the oxygen tension fell to 5 percent. The oxygen consumption as concluded from the graphs presented seemed to be influenced at any concentration less than the normal 20.8 percent. The R.Q. rose with a decrease in oxygen tension. The value in air was 0.98; at 10.3 percent oxygen, 1.10; 5.1 percent, 1.50; 2.0 percent, 1.84; 1.2 percent, 3.2. For turnip tissue the R.Q. varied from the normal value of 1.24 to 1.50 at 5.4 percent oxygen. The leaves of cress showed an average R. Q. of 0.80 at oxygen tensions of 20.9, 16.0, 9.0, 3.3, and 1.4 percent.

As pointed out by Steward, Berry, and Broyer (18), Chevillard and his collaborators did not have a fixed concentration of gas present throughout the entire period of experimentation with a given series. Steward and his group found with a continuous flow of gases of various concentrations of oxygen the potato tissue at 13.0 per cent oxygen had a relative carbon dioxide output of 98.3, assuming 100.0 as normal; at 3.8 percent oxygen, 79.3; and at 1.4 percent, 56.7. These values indicate that the carbon dioxide production was influenced at about 13 or 14 percent oxygen rather than 5 percent. Similar data were presented for carrot and artichoke tissue.

Mack (14) found that there was no significant decrease of the carbon dioxide production at 25° of 100 wheat seedlings until the oxygen content was lowered to 3.1 percent.

Thomas and Fidler (21) reported that in young apples a minimum of carbon dioxide production occurred between 3 and 5 percent oxygen.

Tang (20) in 1933 summarized the more recent studies on the rate of oxygen consumption by plant and animal tissues as a function of the oxygen tension. The oxygen content at the point of influence on the respiration rate is defined as the critical oxygen tension.

Because of the lack of adequate information on the effect of decreased oxygen tension on the oxygen respiration of plant materials and the contradiction of some of this information a study was made on this effect on two varieties of corn. This work is also presented as a precaution to be observed when manometrically measuring the oxygen respiration with a constant volume respirometer of actively respiring material.

With the constant volume type of respirometer and a highly respiring system it is possible conveniently to make such a study. With the continuous removal of oxygen from the gas space by the respiring material we have a means of gradually changing the oxygen tension and at the same

time of measuring the rate of oxygen consumption with the Warburg manometer. Preliminary experiments with milk stage field corn have shown that the critical oxygen tension can be obtained with 10 to 12 grams of material in 2 to 3 hours.

Effect of renewing the oxygen supply on the oxygen respiration of corn.--Stowell's Evergreen corn in the milk and dough stages was used for one study. Four experiments were performed with the respiration rates of the samples differing in each experiment. In all of the experiments 30 kernel samples were used. In experiment 1 and 2 the samples weighed 7.3 to 8.7 grams. With the more mature corn used in experiments 3 and 4 the samples weighed 12.8 to 13.3 grams. Three experiments were made with the Reid's Yellow Dent field corn in different dough stages. The 30 kernel samples weighed 13.1 to 14.6 grams.

In each experiment one sample of the corn was placed in the respirometer and left there undisturbed for 10 to 12 hours. This is called the unaerated sample. Another sample taken from the same ear of corn was given an adequate supply of oxygen continuously. This was accomplished by removing the large ground glass stopper from the respirometer every 2 hours and supplying fresh air to the gas space with the use of a suction. This is known hereafter as the aerated sample.

The data showing the effect of aerating and unaerating respiration samples of Stowell's Evergreen corn are given in table 2 . Similar data for the study on the field corn are given in table 3 . The results from both studies are presented in fig.3 .

As might be expected, the faster the oxidation process the more rapid the depletion of oxygen in the gas space and the more rapid is the decrease in the rate of respiration. This may readily be seen by

Table 2 — Effect of aerating the samples during the respiration tests of Stowell's Evergreen corn at 30°C. The (a) indicates the period during which the aeration was performed.

		: O <sub>2</sub> per gram fresh weight per 15 minute period indicated							
		: Experiment 1		: Experiment 2		: Experiment 3		: Experiment 4	
15 minute periods	Aerated:	Un-	Aerated:	Un-	Aerated:	Un-	Aerated:	Un-	
	: aerated :	: aerated :	: aerated :	: aerated :	: aerated :	: aerated :	: aerated :	: aerated :	
	: cmm.	: cmm	: cmm	: cmm	: cmm	: cmm	: cmm	: cmm	
1	: 89.6	: 92.7	: 67.1	: 67.9	: 66.6	: 65.6	: 59.8	: 58.4	
2	: 98.7	: 91.9	: 67.0	: 67.7	: 68.2	: 67.4	: 58.8	: 58.3	
3	: 87.8	: 90.2	: 66.3	: 66.6	: 66.0	: 65.8	: 57.8	: 57.1	
4	: 86.4	: 87.8	: 64.9	: 65.5	: 64.1	: 63.3	: 55.7	: 56.1	
5	: a	: ---	: a	: ---	: 61.7	: 61.2	: 54.0	: 53.8	
6	: 83.2	: 80.3	: 63.2	: 61.5	: a	: ---	: a	: ---	
7	: 85.6	: 80.4	: 64.7	: 60.4	: 63.7	: 56.0	: 55.2	: 52.0	
8	: 83.7	: 77.4	: 64.7	: 58.9	: 65.0	: 53.6	: 57.2	: 51.1	
9	: 83.1	: 75.1	: 64.8	: 57.9	: 63.1	: 50.3	: 55.4	: 48.9	
10	: 82.5	: 72.6	: 63.3	: 55.6	: 61.8	: 47.8	: 53.9	: 48.3	
11	: 81.1	: 69.9	: 62.2	: 54.3	: ---	: ---	: ---	: ---	
12	: 79.6	: 67.6	: 62.3	: 52.6	: ---	: ---	: ---	: ---	
13	: a	: ---	: a	: ---	: ---	: ---	: ---	: ---	
14	: 76.4	: 62.2	: 61.4	: 49.8	: ---	: ---	: ---	: ---	
15	: 79.7	: 59.5	: 62.7	: 48.2	: a	: ---	: a	: ---	
16	: 79.1	: 55.8	: 61.9	: 45.8	: ---	: ---	: ---	: ---	
17	: 78.6	: 53.4	: 62.2	: 44.4	: ---	: ---	: ---	: ---	
18	: 78.6	: 50.7	: 61.1	: 42.8	: ---	: ---	: ---	: ---	
19	: a	: ---	: a	: ---	: ---	: ---	: ---	: ---	
20	: ---	: ---	: ---	: ---	: 60.5	: 20.2	: 50.6	: 32.2	
21	: ---	: ---	: ---	: ---	: 58.2	: 16.3	: 49.2	: 29.6	
22	: ---	: ---	: ---	: ---	: 55.5	: 13.7	: 47.7	: 27.8	
23	: ---	: ---	: ---	: ---	: ---	: ---	: ---	: ---	
24	: 76.3	: 37.2	: 61.0	: 33.7	: ---	: ---	: ---	: ---	
25	: 75.2	: 33.4	: 62.1	: 30.8	: ---	: ---	: ---	: ---	

Table 3.--Effect of aerating the samples during the respiration tests of Reid's Yellow Dent corn at 30°C. The (a) indicates the period during which the aeration was performed.

15 minute periods	O <sub>2</sub> per gram fresh weight per 15 minute period indicated							
	Experiment 1		Experiment 2		Experiment 3			
	Aerated	Un-aerated	Aerated	Un-aerated	Aerated	Un-aerated		
	Cmm	Cmm	Cmm	Cmm	Cmm	Cmm	Cmm	
1	56.8	56.8	53.2	51.4	33.3	33.5		
2	58.7	57.9	52.4	50.6	34.0	34.5		
3	58.3	57.4	51.2	50.2	33.4	34.1		
4	57.6	56.5	50.2	49.0	33.0	33.4		
5	56.5	55.4	50.0	48.6	33.1	33.4		
6	55.0	53.6	48.5	47.1	32.3	32.9		
7	a	52.3	47.6	46.3	a	31.8		
8	54.6	51.3	a	44.6	32.3	32.1		
9	55.5	48.8	49.0	43.8	33.2	31.8		
10	54.9	46.9	51.2	42.4	32.0	30.6		
11	53.7	45.1	51.4	40.7	31.8	30.3		
12	53.1	42.9	50.9	39.2	31.6	29.8		
13	51.4	40.1	50.2	37.5	31.1	28.9		
14	a	37.3	a	--	a	28.1		
15	--	--	--	--	--	--		
16	--	--	--	--	--	--		
17	--	--	--	--	--	--		
18	51.4	29.9	50.9	30.7	31.3	26.4		
19	50.7	27.8	50.5	28.9	31.0	25.9		
20	49.8	25.2	50.0	27.0	30.9	25.2		
21	--	--	48.5	24.5	--	--		
22	--	--	48.0	23.4	--	--		
23	--	--	a	20.7	--	--		
24	--	--	46.9	18.8	--	--		
25	--	--	48.0	16.8	--	--		
26	--	--	48.0	15.4	--	--		
27	--	--	47.1	13.2	--	--		
28	--	--	46.6	11.4	--	--		
29	--	--	45.5	8.7	--	--		
30	--	--	a	8.7	--	--		
31	--	--	45.9	6.4	--	--		
32	--	--	45.6	5.7	--	--		
33	--	--	44.9	4.4	--	--		
34	--	--	44.3	3.5	--	--		
35	--	--	43.5	2.6	--	--		



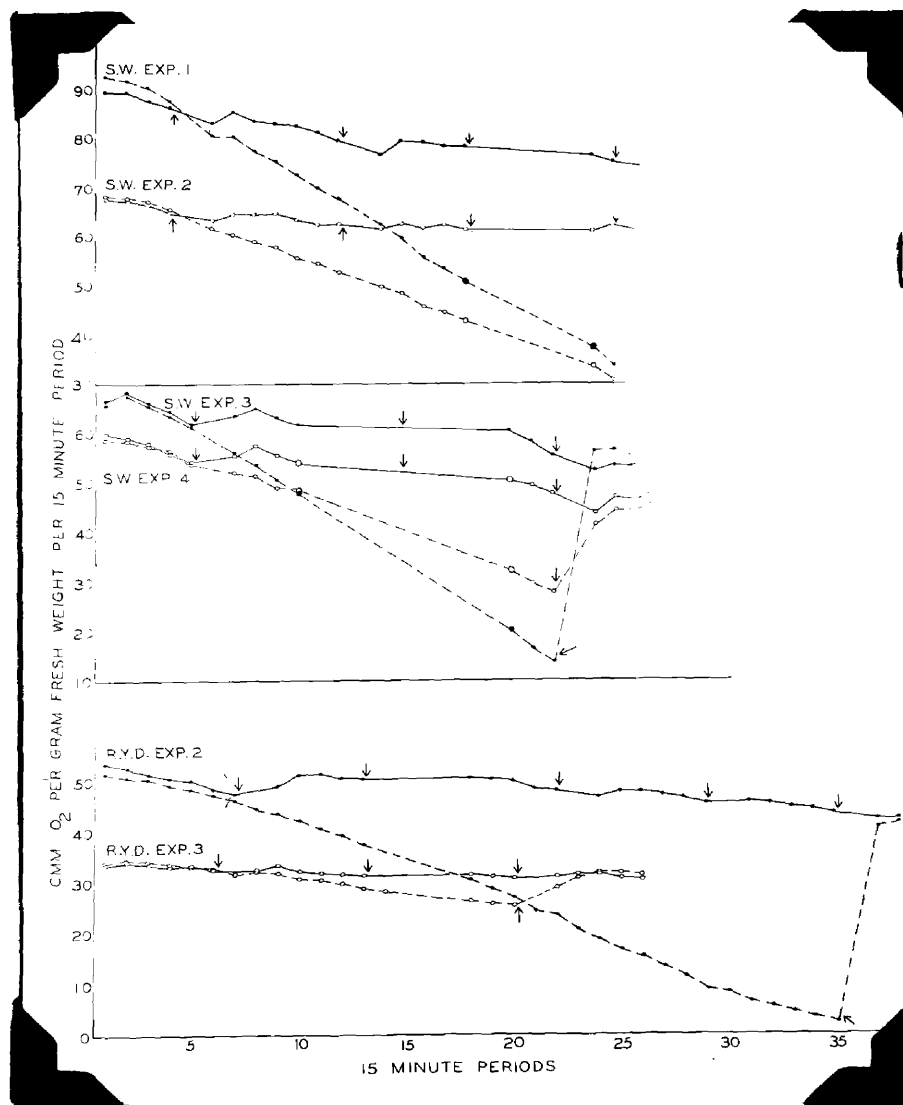


Fig. 3 Effect of aeration and unaeration on the oxygen respiration rate of Stowell's Evergreen and Reid's Yellow Dent corn at 30°C. Arrows indicate points of aeration.

comparing the first four experiments in fig. 2. No accurate conclusion can be drawn, however, by comparing slopes alone since the volumes of the respirometers and the weights of samples in the various experiments are not the same.

There were certain periods when readings could not be taken; during this time the stopcocks were left open. The time when readings were not taken is indicated by the larger dots on the curves. It is concluded that the diffusion of gases is not fast enough to bring the oxygen content back to its normal value in the respirometer when the stopcocks are left open for 60 to 75 minutes. This was shown in all cases by the fact that the slope of the respiration curves remained practically constant.

After sufficient data were obtained with the unaerated samples they were aerated. These points of aeration appear on the right hand side of the graphs. In all cases the respiration rate increased or it appeared that it would increase to the normal rate. The arrows at various points along the curves indicate the times of aeration.

#### Effect of oxygen tension on the oxygen consumed in corn tissue.---

With the data given in tables 2 and 3 and using the graph to supply any missing values from the tables the oxygen tension was calculated at different periods. In the calculation the total amount of oxygen present in the gas space after the alkali solution and respiration sample had been placed in the respirometer was calculated. From this value was subtracted the amount of oxygen absorbed by the tissue. The amount of oxygen remaining was calculated as percent oxygen assuming 20.8 per cent as the normal content. The amount of oxygen consumed during the 2 minutes between the reading of the manometer and the closing of the stopcocks again was always taken into account.

At the end of a 15 minute period the stopcocks were opened. Because of the negative pressure existing in the respirometer due to the absorption of a certain volume of oxygen it was assumed that an equal volume of air rushed into the respirometer. Another volume of air entered the capillary of the manometer equal to one-half the difference of the heights of the manometer fluid multiplied by the cross-sectional area of the capillary. This volume of oxygen was calculated for each opening of the stopcock and was added to that amount of oxygen still remaining. In general, the amount of oxygen present after the stopcock was opened was always greater than before it was opened by approximately 0.208 times the amount of air that rushed into the system. The amount of air rushing into the system was dependent on the amount of oxygen consumed.

Since one sample of the duplicates was always aerated we had the normal respiration rate of the tissue. The percent decrease in respiration was calculated using the data of tables 2 and 3.

The data for the decrease of the respiration rate with the lowering of the oxygen tension are given in tables 4 and 5 and presented graphically in figs. 4 and 5.

The curves for the two varieties of corn are seen practically to coincide except in the lower oxygen tensions where the error in calculation may be large. The critical tension for both varieties of the grain appears to be between 15 and 16 percent oxygen or between 114 and 122 mm of mercury.

It is thus seen that by using actively respiring systems in the constant volume type of respirometer the critical oxygen tension point may be reached. The time required to reach this point will depend on

Table 4 .--The decrease of the oxygen respiration in Stowell's Evergreen corn as affected by decreased oxygen tensions.

Experiment Number								
1	:	2	:	3	:	4	:	
Oxygen Tension	: Decrease in Respiration Percent	Oxygen Tension	: Decrease in Respiration Percent	Oxygen Tension	: Decrease in Respiration Percent	Oxygen Tension	: Decrease in Respiration Percent	
17.8	: 0	18.1	: 0	17.5	: 0	18.5	: 0	
17.0	: 0	17.3	: 0	16.3	: 0	17.6	: 0	
16.3	: 0	16.6	: 0	15.2	: 0	16.9	: 0	
15.5	: 0	16.0	: 0	14.1	: 0	16.1	: 0	
14.2	: 3.5	14.8	: 2.7	11.1	: 12.1	15.4	: 0	
13.5	: 6.1	14.2	: 6.6	10.2	: 17.5	13.9	: 5.7	
12.9	: 7.5	13.5	: 8.9	9.3	: 20.2	13.2	: 10.7	
12.2	: 9.5	12.9	: 10.6	8.5	: 22.6	12.5	: 11.6	
11.6	: 12.0	12.3	: 12.1	3.5	: 66.6	11.9	: 10.4	
11.1	: 13.8	11.8	: 12.6	5.3	: 71.9	7.0	: 36.2	
10.5	: 15.1	11.2	: 15.6	3.1	: 75.3	6.6	: 39.8	
9.2	: 18.6	10.2	: 18.8	---	: ---	6.3	: 41.7	
8.7	: 25.4	9.7	: 23.0	---	: ---	---	: ---	
8.3	: 29.4	9.2	: 26.0	---	: ---	---	: ---	
7.8	: 32.0	8.7	: 28.6	---	: ---	---	: ---	
7.4	: 35.5	6.4	: 44.9	---	: ---	---	: ---	
5.7	: 51.2	6.1	: 50.3	---	: ---	---	: ---	
5.4	: 55.5	---	: ---	---	: ---	---	: ---	

Table 5 .--The decrease of the oxygen respiration in Reid's Yellow Dent corn as affected by decreased oxygen tensions.

Experiment Number						
1		2		3		
Oxygen Tension	Decrease in Respiration	Oxygen Tension	Decrease in Respiration	Oxygen Tension	Decrease in Respiration	
Percent	Percent	Percent	Percent	Percent	Percent	Percent
18.9	0	18.2	0	19.7	0	
17.9	0	17.3	0	19.1	0	
17.0	0	16.4	0	18.5	0	
16.0	0	15.5	0	17.9	0	
15.2	0	14.7	0	17.4	0	
14.3	2.6	11.5	10.5	16.8	0	
12.6	6.1	10.7	17.1	16.3	0	
11.8	12.2	10.0	20.8	15.8	0	
11.0	14.5	9.3	23.0	15.3	4.3	
10.3	15.9	8.7	25.4	14.8	4.5	
9.6	19.1	6.4	39.6	14.3	5.0	
9.0	21.9	5.9	42.7	13.8	5.7	
6.3	41.8	5.5	46.0	13.3	7.0	
5.9	45.2	5.0	49.4	11.1	15.5	
5.5	49.3	4.6	51.2	10.6	16.5	
---	---	4.3	55.8	10.2	18.6	
---	---	4.0	59.9	---	---	
---	---	3.7	65.0	---	---	
---	---	3.5	67.9	---	---	
---	---	3.3	71.9	---	---	
---	---	3.1	75.5	---	---	
---	---	2.7	86.0	---	---	
---	---	2.6	87.5	---	---	
---	---	2.5	90.2	---	---	

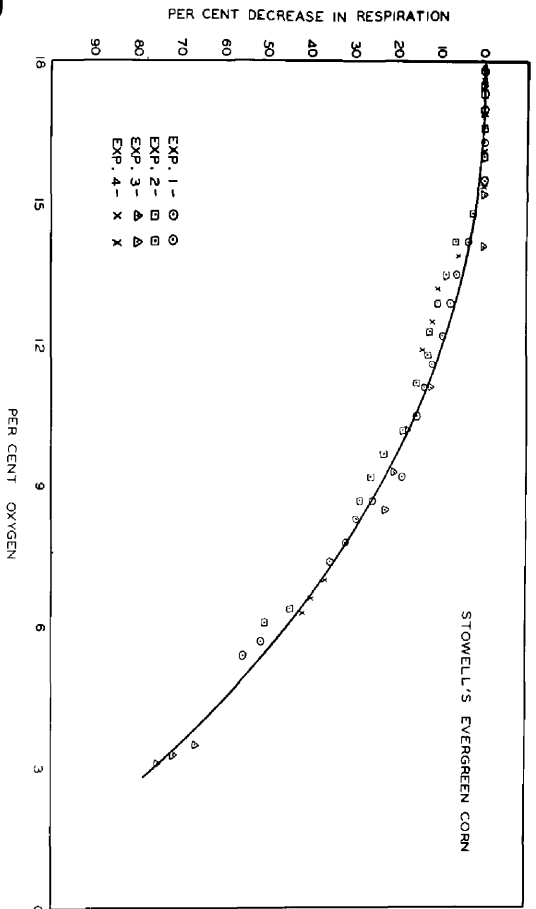


Fig. 4 The effect of the percent oxygen on the oxygen respiration of Stowell's Evergreen corn.

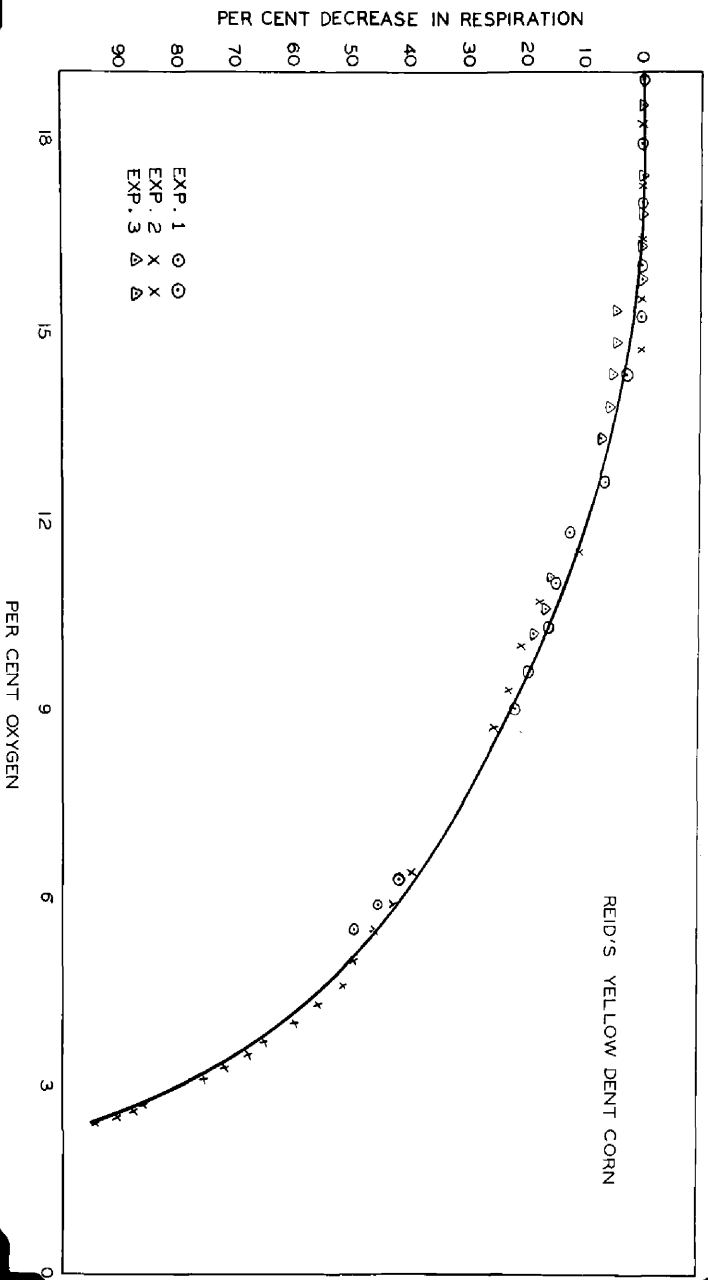


Fig. 5 The effect of the percent oxygen content on the oxygen respiration of Reid's Yellow Dent corn.

the size of the sample, the rate of oxygen respiration, the volume of the respirometer, and the critical oxygen tension of the material. The smaller the sample, the lower the rate of respiration, and the larger the respirometer the less likelihood will there be of depleting the oxygen supply to the point of influence on the respiration rate.

## ANALYTICAL METHODS

Sampling.---Three rows of kernels, plus the residual kernels left in the row from which the respiration sample was taken, were removed from each ear of corn in each lot. After the sample was ground to a fine pulp in a Nixtamal mill it was thoroughly mixed and samples were removed for analysis.

Moisture.---From 4 to 5 g of pulp were weighed in a tared watch glass and dried to constant weight in a vacuum oven at 80°C under 3 to 4 cm pressure. Entire corn kernels were dried when the sample contained less than 45 to 50 percent moisture. Unground wheat kernels were used for the moisture determinations.

Sugars.---A sample of 16 g of pulp was weighed into a counterpoised 200 cc Kohlrausch sugar flask and covered immediately with 75 cc of boiling 95 percent alcohol. Samples consisting of 16 to 20 g of wheat kernels were placed in mortars and covered with 75 cc of boiling 95 percent alcohol. After the sample was ground to a fine pulp the extract and pulp were transferred to a 200 cc Kohlrausch flask. The samples were brought to a boil on the steam bath soon after adding enough water to reduce the alcohol to 70 percent and the boiling continued for 30 minutes to extract the sugars. After cooling, the flasks were made to volume with 95 percent alcohol. Just before making a determination the flasks were again adjusted to volume with 95 percent alcohol. The reducing sugars were determined according to the Munson and Walker gravimetric procedure (16). Total sugars were determined by hydrolyzing 50 cc of the clarified extract from the reducing sugar determination with 5 cc of concentrated hydrochloric acid. The hydrolysis was allowed to take place



for 12 hours at 38° to 40°C. The solutions were made to volume and the reducing sugars in a neutralized portion of the sample was determined as previously described. The total and reducing sugars and sucrose were calculated as percentages of the wet weight.

## EXPERIMENTAL RESULTS

Relation of Respiration to Moisture and Sugar Content  
at Different Stages of Ripening  
Sweet Corn

Experiment 1.---Stowell's Evergreen corn grown on the University farm was used for part of the 1936 study. Six ears in the same stage of ripening, as determined by the "thumb nail" test(1), were selected at each sampling date except for the last two samplings. These contained only two ears.

The method of removing the kernels from the cob was the same in all of the corn studies. After the husks were laid back, a deep V-cut was made in one row of kernels. All of the wounded tissue was removed by cutting inwardly at the bottom of the V-cut. In this way one row of kernels was completely removed and access could be gained to the neighboring row of kernels from which the respiration samples were taken. To remove the kernels a deep horizontal cut was made, severing only the peduncle attachment. Ten kernels from the middle of the row from each of the ears were removed. The sample taken from each ear was placed in a respirometer and tested for one hour.

The time that elapsed from picking until the respiration samples were placed in the respirometers was no more than one hour. All the corn samples were left in the respirometer 30 minutes before readings were made. The samples for moisture and sugar determinations were prepared between respiration readings.

The weight of the 10 kernel samples varied from 1.83 grams in the first sample of corn which was always in the milk stage to 6.50 grams when the corn contained 34 percent moisture. The greatest variation in the respiration activity was observed in the milk stage samples in which the highest was 481 and the lowest 393 cmm oxygen. All of the respiration

data have been calculated on the basis of the cmm oxygen absorbed per 1 gram fresh weight per hour period. The respiration values for the samples given in the following tables are the average of all the tests made at any sampling date.

The results of the corn collected at 7 different times during the ripening period are given in table 6 and shown graphically in figure 6.

Experiment 2 . The study with sweet corn was repeated in 1937 with the same variety of corn, but which was grown on a different area on the University Farm. Six ears of the corn were again used for each test. Ten kernels were removed from each ear, 5 of which were placed in one respirometer and 5 in another, making a total of 30 kernels in each of the two tests. The weights of the 30 kernel samples varied from 7.3 grams for milk stage kernels to 13.3 grams when the corn contained 35 percent moisture. The results of this study are given in table 6 and are shown graphically in figure 6.

The results of experiments 1 and 2 as plotted in figure 6 aim to show only the levels of the moisture, sugar and respiratory activity at the time of sampling. The curves may only show the general trend since there was considerable variation in the respiration results in different samples collected at any one time. When more than one sample was taken at a sampling date only one set of data was plotted in figure 6. The sample the data of which was used is starred (\*) in table 6.

With corn in the milk stage there is considerable variation in the sugar content which at this time does not seem to cause much difference in the rate of respiration. In 1937 one sample of the milk stage corn contained 7.39 and another 6.29 percent total sugar; the reducing sugar was 22 and the sucrose content was 12 percent lower in the second sample, but

Table 6 .---Respiration at 30°C. and percentage of moisture and sugar in Stowell's Evergreen corn at different stages of ripening. The asterisks indicate the samples the values of which were plotted in fig. 6 when more than one sample was collected at any one sampling period.

1936 Experiment						
Date of Sampling	O <sub>2</sub> per gram fresh weight per hour	Moisture Percent	Total Sugars Percent	Sucrose Percent	Reducing Sugar Percent	
Aug. 18	431.3	80.11	7.69	4.94	2.49	
Aug. 31	275.8	68.93	3.45	2.36	0.97	
Sept. 5	264.5	66.40	3.35	2.26	0.97	
Sept. 10	254.5	58.98	3.17	1.93	1.14	
Sept. 17	203.1	49.83	2.75	1.56	1.11	
Sept. 25	60.1	41.22	2.12	1.28	0.77	
Sept. 25*	133.3	37.73	2.04	1.28	0.69	
Sept. 25	105.2	31.52	2.84	1.86	0.88	
Oct. 2	115.7	34.20	2.88	2.00	0.77	
1937 Experiment						
Aug. 20*	415.0	79.22	7.39	4.86	2.27	
Aug. 20	412.6	78.33	6.29	4.28	1.78	
Aug. 30	295.1	71.10	4.26	2.77	1.34	
Aug. 30*	287.0	69.93	4.68	2.88	1.65	
Sept. 10	263.6	68.60	3.99	2.84	1.00	
Sept. 10*	231.1	56.88	3.45	2.19	1.14	
Sept. 17	200.7	47.53	4.05	2.41	1.51	
Oct. 8	46.6	35.39	3.40	2.42	0.85	
Nov. 3	57.3	30.35	--	--	--	

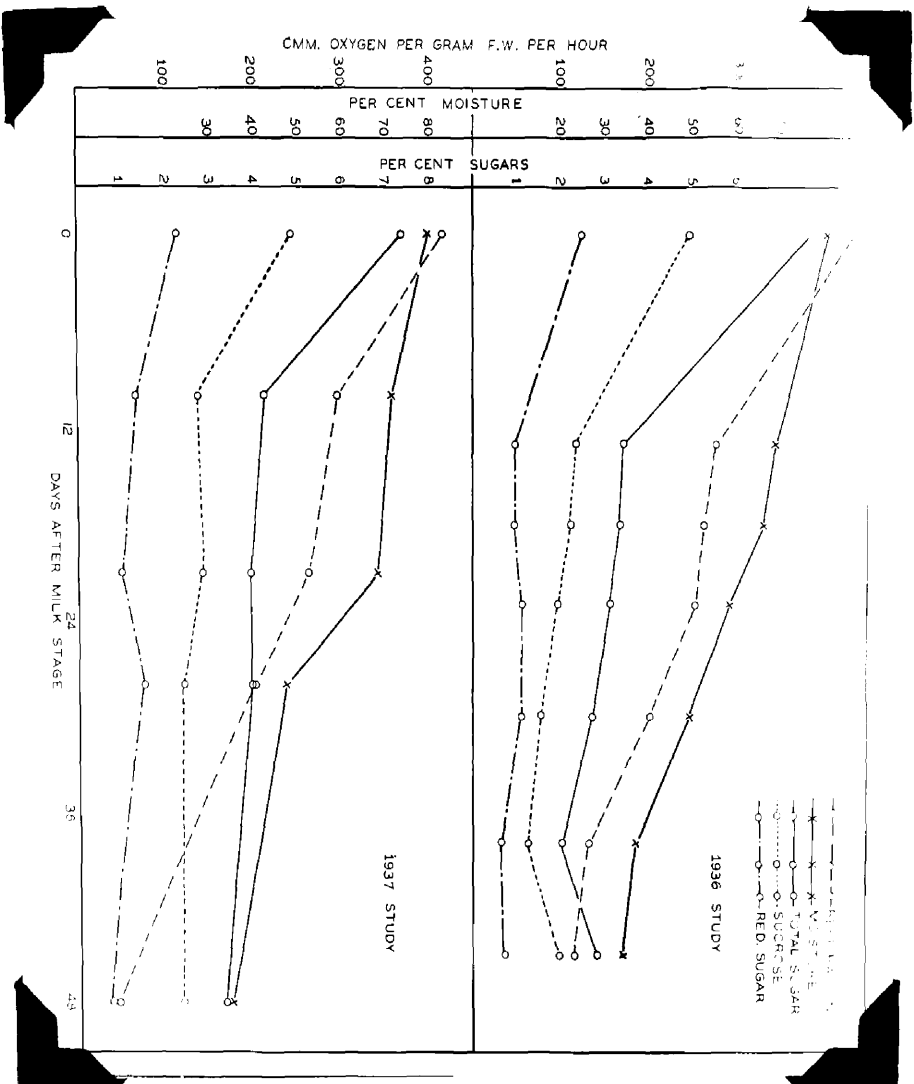


Fig. 6 The oxygen respiration at 50°C., moisture, and sugar content in Stowell's Evergreen corn at different stages of ripening.

the respiration rates of the two samples was practically identical with 415 and 413 cmm of oxygen consumed per gram in one hour. The general trend of the curves for the experiments in the two years indicate that sweet corn in the milk and dough stages shows a relatively close correlation between respiratory activity and the sugar content as compared with kernels in the later stages of ripening when they contained 40 to 45 percent moisture.

The parallelism between the natural moisture and the respiration curves is very close in the experiments for both years except in the milk stage, where there is a crossing of the curves. After the moisture was reduced to 70 percent the curves seem to be rather closely correlated. One extreme variation from the general trend shown by the respiration and moisture curves is given in the 3 samples collected on September 25, 1936. The moisture percentages of the samples were 41.2, 37.7, and 31.5, with the respiration rates corresponding as 60, 133, and 105 cmm. oxygen. The data from this single experiment show the variation in the rate at which the moisture is reduced in the kernels, but probably of greater importance is the indication that the total moisture in the kernel may not necessarily be the controlling factor that conditions the respiratory intensity but that the form of water present, whether free or bound, is the more important. It is very likely that determinations of the free and bound water in kernels in these later stages will prove to be very important in explaining these differences in respiratory intensity.

#### Field Corn

Experiment 1.---Reid's Yellow Dent corn grown on the University farm was used for the 1936 experiments on field corn. In the first 4 tests 6 ears were selected and 10 kernels removed from each ear for a respiration test. At the last 2 sampling dates 2 ears were used for the tests.

The 10 kernel samples varied in weight from 2.1 grams for milk stage kernels to 6.6 grams when the kernels contained 46 percent moisture. The variation in the different respiration rates in the samples removed from each ear at any one sampling date was again the greatest in milk stage corn, the lowest value was 300 and the highest 389 cmm oxygen. The respiration values given in the following tables are the average of all the tests made at any given sampling. The results of the field corn collected at 6 different stages of ripening are given in table 7 and presented graphically in fig. 7.

Experiment 2.—The study with field corn was repeated in 1937 with corn that was grown on the same plot from which the 1936 material was received. Six ears of corn were again used at each sampling period. Ten kernels were removed from each ear, 5 of which were placed in one respirometer and 5 in another with a total of 30 kernels in each. The weights of the 30 kernel samples varied from 9.1 grams for milk stage kernels to 18.1 grams for kernels with 46 percent moisture. The results of this study are given in table 7 and presented graphically in figure 7.

The results for experiments 3 and 4 as presented in figure 7 do not aim to show a time rate of change of moisture, sugars, and respiration but the levels of these at various stages of ripening. The variation in samples collected at the same time is shown in table 7. The starred\* samples indicates the data used in figure 7 when more than one sample was collected at any one sampling date.

From the 1956 study it appears that there is a rather abrupt decrease in total sugars and respiration when the moisture in the

Table 7.--Respiration at 30°C. and percentage of moisture and sugar in Reid's Yellow Dent corn at different stages of ripening. The asterisks indicate the samples the values of which were used in fig. 7 when more than one sample was collected at any one sampling date.

1936 Experiment						
Date of Sampling	O <sub>2</sub> per gram fresh weight per hour	Moisture Percent	Total Sugars Percent	Sucrose Percent	Reducing Sugar Percent	
Aug. 20	337.4	73.17	4.57	2.63	1.80	
Sept. 3	329.8	74.72	3.84	2.22	1.50	
Sept. 8	241.5	56.84	2.88	1.76	1.03	
Sept. 22	141.1	37.48	2.13	1.50	0.55	
Sept. 25	168.8	46.54	1.09	0.71	0.34	
Sept. 25*	143.1	41.99	2.42	1.87	0.45	
Sept. 25	90.2	35.94	0.86	0.66	0.17	
Oct. 2	60.5	30.12	0.45	0.28	0.15	
1937 Experiment						
Aug. 13*	333.9	75.09	4.95	2.85	1.95	
Aug. 13	294.3	70.00	3.78	2.23	1.43	
Aug. 18*	259.5	66.58	2.71	1.72	0.90	
Aug. 18	267.1	69.71	3.01	1.79	1.13	
Aug. 27*	208.0	57.85	2.28	1.29	0.92	
Aug. 27	204.0	56.81	2.09	1.09	0.94	
Sept. 9*	148.8	46.43	2.02	1.34	0.61	
Sept. 9	130.6	36.67	2.16	1.51	0.57	
Sept. 16	120.4	34.78	2.20	1.51	0.61	



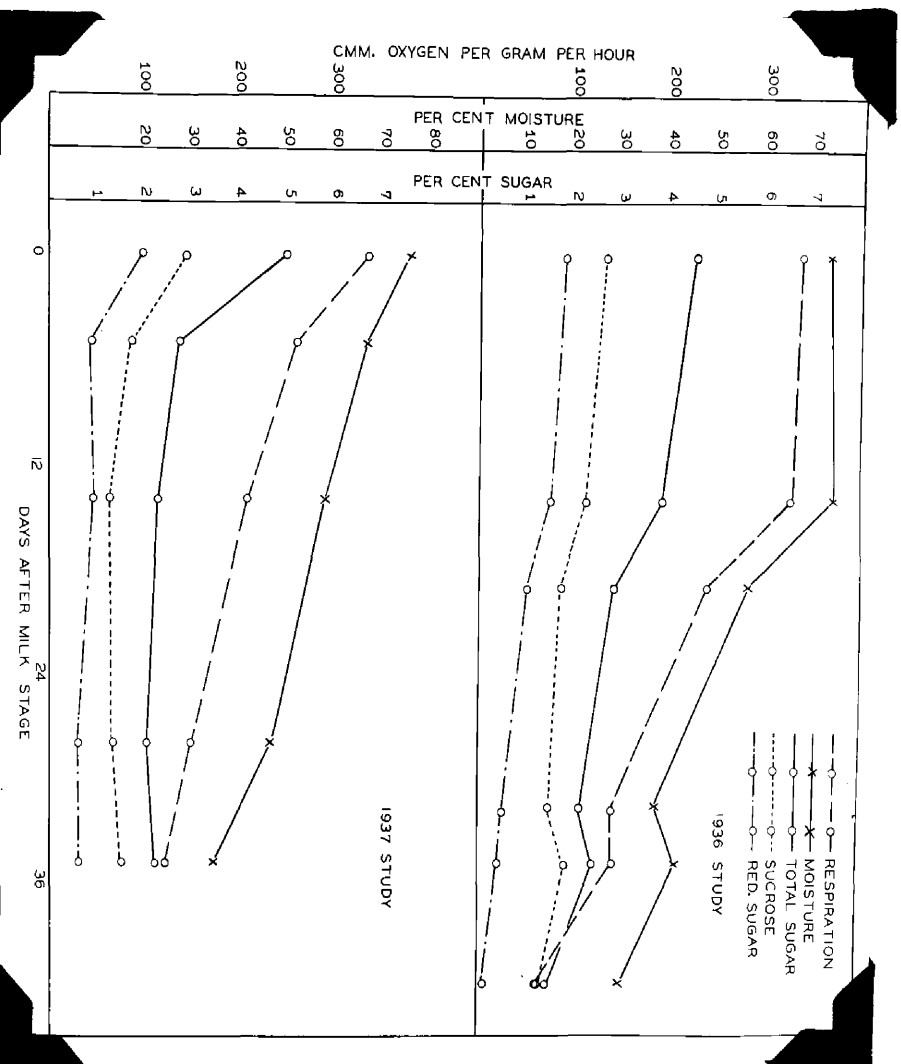


Fig. 7. The oxygen respiration at 30° C., moisture and sugar content of Reid's Yellow Dent field corn at different stages of ripening.

corn was reduced to 35 to 36 percent in the later stages of ripening. This sudden decrease was not observed with the corn in the 1937 experiment, however, the sugar and respiration curves parallel rather closely in the stages previous to the time when the kernels have 40 percent moisture.

There is some parallelism between the respiration and sugar curves but there seems to be a closer relationship between the rate of respiration and the moisture. The correlation for the field corn is closer than that for the sweet corn. The variation in the several samples collected at any one time is less for the field corn. When variations in the respiration samples existed they were in the same direction as the moisture content.

#### Wheat

Leapland wheat grown on the University farm was used for this study. For the first sample which was taken on June 4, 1937, 25 heads were collected; in every sample thereafter 40 heads were used. Samples were taken from the time the kernels were in the milk stage with 61 percent moisture until they contained 17 to 18 percent.

The time that elapsed from cutting the grain until the respiration samples were placed in the respirometers varied from 30 to 60 minutes. Considerable care had to be exercised in handling the green immature kernels so that they might not be wounded. In the first test each duplicate respiration sample contained one kernel from the middle portion of each head or a total of 25 kernels. In each test thereafter 40 kernels was placed in each of the two respirometers. In the first test the average weight of the 25 kernels was 1.005 grams. The 40 kernel samples varied in weight from 2110 grams on

June 7 to 2.665 grams on June 18 and then steadily decreased in weight till 40 kernels weighed 1.690 grams on July 1. The respiration samples were left in the respirometers 30 minutes before the tests were begun and then tested continuously over a period of 10 hours at 28°C.

In some of the respiration tests triplicate samples of 1 cc each of the alkali solution were removed from the respirometers and the carbon dioxide content determined by the titration method suggested by Gore (11). Table 8 shows the value of the respiratory quotient of wheat kernels at different stages of ripening and the oxygen consumed per gram fresh weight per hour for 10 hour periods. The data for this study are presented graphically in figure 8.

The figures given at the end of some of the respiration curves indicate the calculated percent oxygen still present in the respirometers. Respiration samples taken after June 10 had oxygen concentrations greater than 17 percent. It was assumed that this concentration had no depressing effect on the amount of oxygen consumed. The critical oxygen tension for wheat was not determined.

The respiratory quotient of wheat kernels in the milk stage was 1.02 and remained nearly unity throughout the entire ripening period.

In figure 8 is shown the time rate of respiration curves for wheat at different stages of ripening. It is important to note that immature wheat kernels with a given moisture percentage do not respire at a constant rate after removal from the head but show an appreciable decrease. This decrease cannot be attributed

Table 8.—The respiration at 28°C. and moisture content of Leapland wheat kernels at different stages of ripening.

Date of Sampling	Moisture	CO <sub>2</sub>	O <sub>2</sub> per hour per gram fresh weight for hour periods indicated										
		O <sub>2</sub>	1	2	3	4	5	6	7	8	9	10	
	Percent		Cmm	Cmm	Cmm	Cmm	Cmm	Cmm	Cmm	Cmm	Cmm	Cmm	Cmm
June 4	61.00	---	472.5	454.6	443.0	420.6	414.8	397.7	390.3	371.6	364.1	---	---
June 7	56.92	1.02	383.4	359.7	334.3	314.3	297.1	285.6	274.2	270.9	263.0	249.4	---
June 8	54.93	0.99	349.1	326.7	305.7	286.3	275.9	261.5	251.6	247.4	243.8	240.1	---
June 9	52.20	1.04	340.7	307.9	279.1	249.1	224.6	196.6	164.7	---	---	---	---
June 10	50.56	---	324.8	300.1	282.4	252.2	229.0	---	---	---	---	---	---
June 12	47.55	---	293.3	271.9	254.7	238.6	225.8	213.7	205.8	196.0	---	---	---
June 14	46.11	1.04	255.9	243.9	229.1	221.5	210.4	199.8	194.1	189.6	184.9	182.3	---
June 16	42.16	---	193.1	186.4	173.2	167.4	159.1	152.0	147.1	144.0	138.5	138.1	---
June 18	41.34	---	154.0	142.7	139.2	128.4	127.6	122.8	124.4	---	---	---	---
June 21	30.94	0.99	58.5	59.6	58.9	57.3	54.0	55.2	51.8	50.5	48.8	46.0	---
June 22	27.54	---	66.6	61.1	63.8	60.0	56.7	61.2	60.7	53.2	54.3	53.1	---
June 28	22.60	---	28.6	21.8	21.3	19.6	18.1	17.0	16.9	15.0	12.2	16.7	---
June 29	17.60	---	---	---	3.4	---	---	3.6	---	---	---	4.4	---
June 30	23.93	1.00	29.9	26.6	17.4	---	---	18.6	17.0	22.7	12.3	15.4	---
July 1	18.27	---	---	---	3.4	---	---	4.6	---	---	4.7	4.0	---

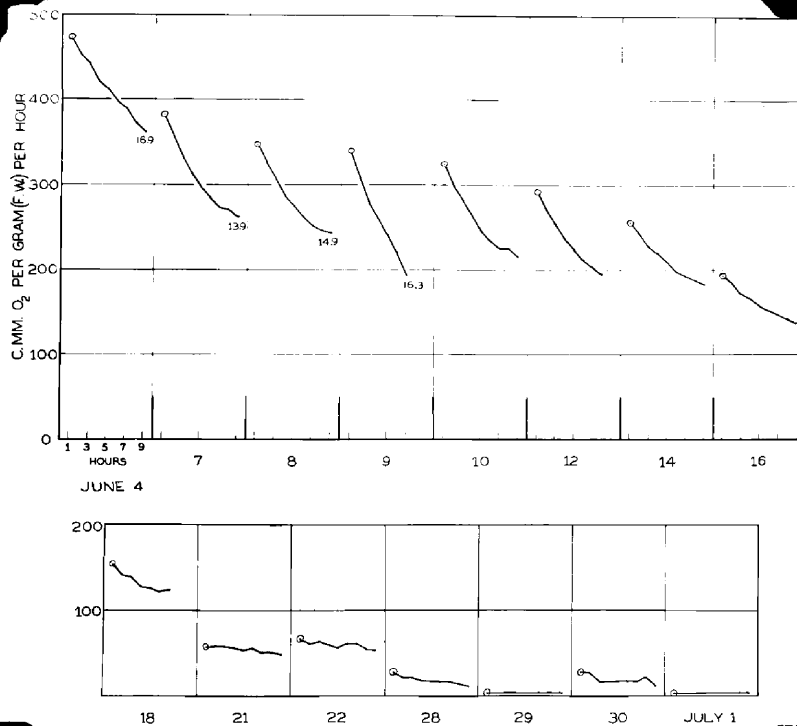


Fig. 8. The time rate of respiration curves at 28°C of wheat kernels at different stages of ripening. The figures at the end of some of the curves indicate the percent oxygen in the respirometer at that time.

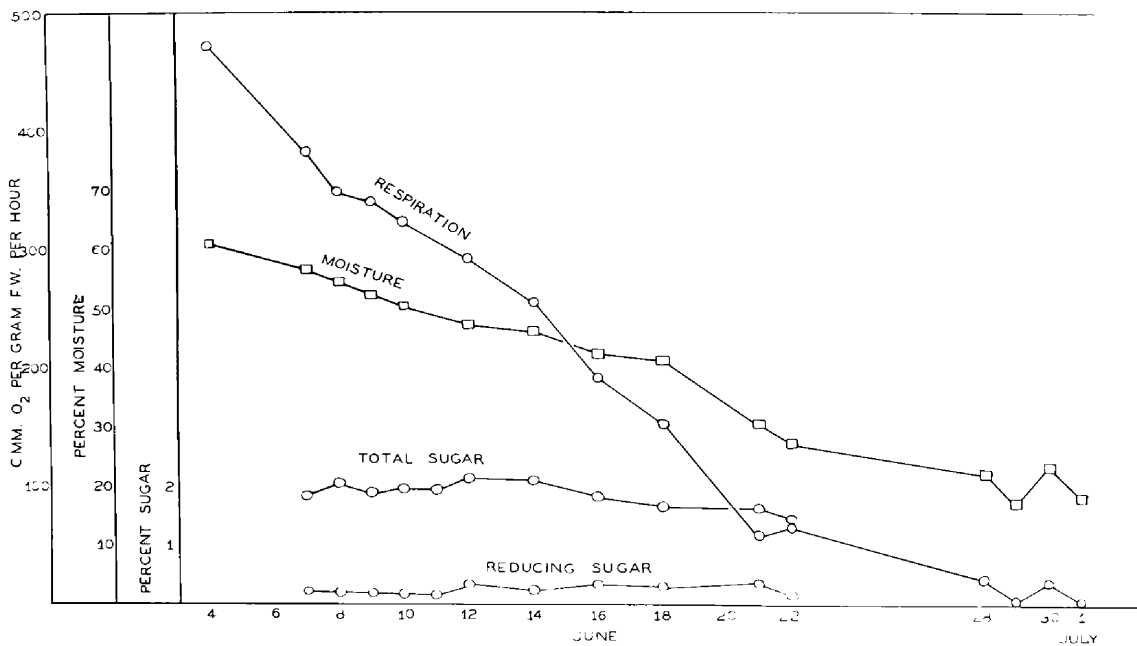


Fig. 9. The relationship between the moisture and the oxygen respiration at 28°C. of wheat kernels of different stages of ripening.

to a decrease in moisture. The respiration sample collected on June 7 which had an initial moisture content of 56.92 percent had 56.03 percent 24 hours after sampling. As the kernels ripen the time rate of respiration decreases less rapidly and finally reaches a constant rate when the moisture has been reduced to 30 percent. It rained during the evening of June 29 and early morning of June 30. The moisture percent increased from 17.6 to 23.9 a percentage increase of 35.7 due to water imbibed from the air and rain when the grain was in the shock. The respiration of the sample with increased moisture decreased from 30 cmm to 15 cmm of oxygen. The respiration increased from an average of 3.8 for the sample with 17.6 moisture to 20.0 cmm oxygen for the sample with 23.9 percent moisture, an increase of 426 percent. It is important to notice that respiration of the samples with 22.6 and 23.9 percent moisture decreased considerably after the third and fourth hours and was not constant throughout the entire period of the test.

The circled values in the respiration curves given in figure 8 were plotted together with the moisture and sugar contents against the time of sampling. The data presented in figure 9 shows that respiration and moisture curves parallel for a short time just before crossing. The respiration rate decreases more rapidly for a time when the kernels have about 40 to 45 percent moisture and then the curves parallel again. Determination of the free and bound water will prove to be very important in explaining the change in respiratory activity at the crossing point of the two curves. Determinations of the ratio of free to bound water will also probably prove important in explaining the change in respiration in wheat after the moisture percentage has been increased by the imbibition of water as

was shown for the sample collected on June 30. The data also show that the respiration is not correlated with the sugar content.

Time Rate of Respiration and Sugar Content after  
Storage at Different Temperatures.

Sweet Corn

Experiment 1.--The substrate used in the process of respiration in plants has received considerable attention, and it is well established that carbohydrates furnish the greater part of the materials used in the oxidation process. In this experiment the time rate of respiration was determined in corn in which the sugar percentages varied in different lots because of different storage conditions.

In the 1936 study the 6 ears of sweet corn used for the first four tests in the study on the relation of respiration to the moisture and sugar content at different stages of ripening were divided into 2 lots of 3 ears each. One lot was placed in a General Electric refrigerator which maintained a temperature of  $5^{\circ} \pm 0.5^{\circ}\text{C}$ ; the other lot was placed in an insulated box which maintained a temperature of  $30^{\circ} \pm 0.2^{\circ}\text{C}$ . After 4 days of storage respiration samples with 10 kernels in each were again removed from each ear. In all of these experiments the respiration samples were removed as previously described. When the second sample was taken the ear was turned around and the kernels removed from a row opposite the position of the first sample. Since the same lot of corn was used for two different studies some of the data will appear twice.

When the corn was stored the ears with the husks laid back in the normal position were wrapped with wax paper which was held in place with rubber bands. Holes were made in the paper to allow for aeration. This procedure prevented excessive loss of moisture from the kernels, especially when stored at  $30^{\circ}\text{C}$ .



In the 1936 study a sugar analysis was made 2 hours after picking on the entire lot of 6 ears before storage and then a similar analysis on each of the 2 lots after the storage period.

The 10 kernel respiration samples varied from 1.8 to 2.6 grams for milk stage kernels and from 4.5 to 5.5 grams for late dough stage kernels. The samples were left in the respirometers 30 minutes before readings were started and then were tested continuously for the next 6 hours. The sugar and moisture changes are given in table 9. The respiration data for the same samples are given in table 10. The combined data are presented graphically in figure 10.

Experiment 2.—The study of the effect of storage at 5° and 30° on the oxygen respiration and sugar content of green sweet corn in the milk and early dough stages was repeated in 1937. The 12 ears of corn used for the first two tests in the study on the changes that take place during the ripening process were divided into 2 lots of 6 ears each. One lot was stored at 5° C. and the other lot at 30° C. for 4 days. At the end of the storage period samples were again taken. The study in 1937 differed from the procedure used in the previous experiment in that a sugar analysis was made 2 hours after picking on each lot before storage. The selection of respiration samples also differed from the preceding experiment in that 10 kernels were removed from each of the 6 ears in one lot, 5 of which were placed in one respirometer and 5 in another. The 30 kernel respiration samples varied from 7.3 to 7.9 grams for milk stage kernels and from 11.8 to 12.5 grams for early dough stage kernels.

The results of the sugar and moisture changes are given in table 11. The respiration data for these same samples are given in table 12. The combined data are presented graphically in figure 10.

Table 9.—The moisture and sugar content of Stowell's Evergreen corn used for the respiration tests given in table 10.

Stage of ripening:	Treatment	Moisture :Percent	Total : Sugar : Percent	Reducing : Sugar : Percent	Sucrose :Percent
	:Two hours after picking on Aug. 18	: 80.11	: 7.69	: 2.49	: 4.94
Milk	:After 4 days storage at 5°C.	: 79.84	: 5.62	: 1.90	: 3.53
	:After 4 days storage at 30°C.	: 76.05	: 3.06	: 1.13	: 1.83
	:Two hours after picking on Aug. 31	: 68.93	: 3.45	: 0.97	: 2.36
Early Dough	:After 4 days storage at 5°C.	: 69.53	: 2.22	: 0.90	: 1.25
	:After 4 days storage at 30°C.	: 69.02	: 1.35	: 0.64	: 0.67
	:Two hours after picking on Sept. 10	: 58.99	: 3.17	: 1.14	: 1.93
Dough	:After 4 days storage at 5°C.	: 58.96	: 2.72	: 0.96	: 1.67
	:After 4 days storage at 30°C.	: 55.94	: 1.18	: 0.69	: 0.47
	:Two hours after picking on Sept. 17	: 49.83	: 2.75	: 1.11	: 1.56
Late Dough	:After 4 days storage at 5°C.	: 49.46	: 2.50	: 0.98	: 1.44
	:After 4 days storage at 30°C.	: 47.07	: 1.97	: 0.89	: 1.03

Table 10.--Effect of storage at 5° and 30°C. on the oxygen respiration at 30°C. of Stowell's Evergreen corn at different stages of ripening.

Stage of ripening:	Treatment	O <sub>2</sub> per hour per gram fresh weight for hour period indicated					
		1	2	3	4	5	6
		Cmm	Cmm	Cmm	Cmm	Cmm	Cmm
Milk	Two hours after pick- ing on Aug. 18	428.3	425.3	422.9	404.6	381.4	365.4
	After 4 days storage at 5°C.	398.6	404.2	407.8	398.2	381.0	360.2
	Two hours after pick- ing on Aug. 18	434.2	429.8	429.1	415.0	395.3	381.5
	After 4 days storage at 30°C.	264.8	258.9	250.7	241.0	234.7	225.8
	Two hours after pick- ing on Aug. 31	277.2	270.9	260.6	237.1	222.7	203.0
	After 4 days storage at 5°C.	238.1	240.0	233.6	224.5	207.8	193.9
Early Dough	Two hours after pick- ing on Aug. 31	268.2	261.5	248.8	225.0	213.2	195.9
	After 4 days storage at 30°C.	164.1	159.0	155.3	154.5	147.6	138.1
	Two hours after pick- ing on Sept. 10	256.6	252.2	246.5	233.3	223.3	211.0
	After 4 days storage at 5°C.	242.6	246.4	245.6	228.2	214.6	200.5
	Two hours after pick- ing on Sept. 10	252.3	244.0	236.6	223.4	211.1	198.0
	After 4 days storage at 30°C.	127.9	128.6	133.6	124.7	121.4	117.9
Late Dough	Two hours after pick- ing on Sept. 17	212.1	211.9	211.8	203.5	193.9	186.5
	After 4 days storage at 5°C.	211.2	212.2	208.4	201.8	191.8	182.2
	Two hours after pick- ing on Sept. 17	194.2	191.6	190.4	181.0	173.1	167.1
	After 4 days storage at 30°C.	92.9	100.1	100.1	98.0	94.2	96.6

Table 11.--The moisture and sugar content of Stowell's Evergreen corn used for respiration tests given in table 12.

Stage of ripening:	Treatment	Moisture	Total Sugar	Reducing Sugar	Sucrose
		:Percent	:Percent	:Percent	:Percent
Milk	:Two hours after picking on Aug. 20	: 78.33	: 6.29	: 1.78	: 4.28
	:After 4 days storage at 5°C.	: 77.68	: 4.66	: 1.67	: 2.84
	:Two hours after picking on Aug. 20	: 79.22	: 7.39	: 2.27	: 4.86
	:After 4 days storage at 30°C.	: 74.15	: 3.40	: 1.07	: 2.19
	:	:	:	:	:
	:	:	:	:	:
Early Dough	:Two hours after picking on Aug. 30	: 71.10	: 4.26	: 1.34	: 2.77
	:After 4 days storage at 5°C.	: 71.66	: 3.11	: 0.97	: 2.03
	:Two hours after picking on Aug. 30	: 69.94	: 4.68	: 1.65	: 2.88
	:After 4 days storage at 30°C.	: 69.39	: 2.07	: 1.43	: 0.61
:	:	:	:	:	
:	:	:	:	:	

Table 12.--Effect of storage at 5° and 30°C. on the oxygen respiration at 30° C. of Stowell's Evergreen corn at different stages of ripening.

Stage of ripening:	Treatment	O <sub>2</sub> per hour per gram fresh weight for hour period indicated					
		1	2	3	4	5	6
		Cmm	Cmm	Cmm	Cmm	Cmm	Cmm
Milk	:Two hours after pick- :ing on Aug. 20	: 412.6:	: 386.3 :	: 398.1 :	: ----- :	: 390.0 :	: 381.0 :
	:After 4 days storage : at 5°C.	: 399.2:	: 395.0 :	: 368.7 :	: 358.0 :	: 355.5 :	: 322.9 :
	:Two hours after pick- :ing on Aug. 20	: 415.0:	: 392.0 :	: 392.4 :	: ----- :	: 367.4 :	: 351.8 :
	:After 4 days storage : at 30°C.	: 327.8:	: 301.1 :	: 274.7 :	: 261.4 :	: 257.4 :	: 248.6 :
Early Dough	:Two hours after pick- :ing on Aug. 30	: 295.1:	: 285.1 :	: 277.4 :	: ----- :	: 251.2 :	: 258.4 :
	:After 4 days storage : at 5°C.	: 284.5:	: 272.4 :	: 271.7 :	: 264.0 :	: ----- :	: ----- :
	:Two hours after pick- :ing on Aug. 30.	: 287.0:	: 277.2 :	: 275.1 :	: ----- :	: 254.5 :	: 262.8 :
	:After 4 days storage : at 30°C.	: 182.5:	: 176.6 :	: 172.3 :	: 169.0 :	: ----- :	: ----- :

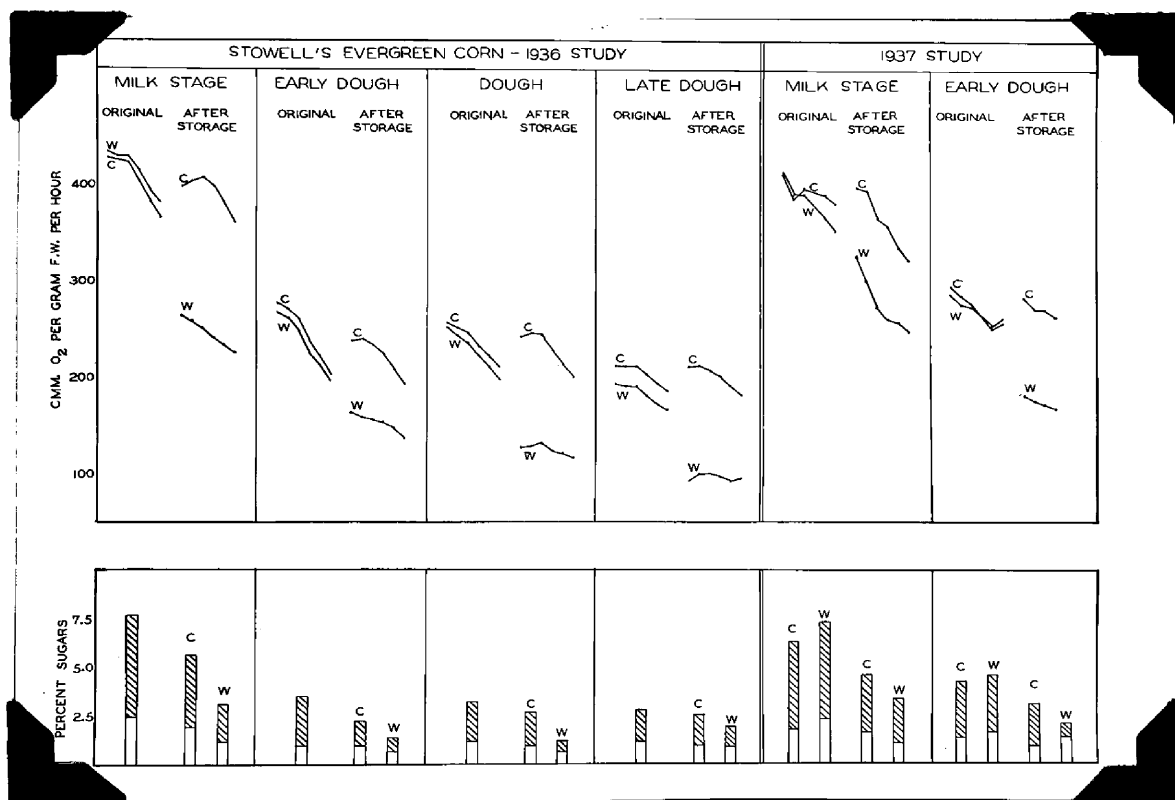


Fig. 10. Effect of cold (5°C.) and warm (30°C.) storage on the oxygen respiration at 30°C. and sugar content of Stowell's Evergreen corn. The height of the columns indicates total sugars and the open portions reducing sugars. C--cold stored for four days; W--warm stored for four days.

In table 13 are calculated the percentage losses of the respiration and sugars for the 4 different stages of corn used in the 1936 experiment and the 2 experiments repeated in 1937. The milk and early dough stage corn in the 2 years show the same general trends except for the loss of reducing sugar in the 1937 early dough stage corn. The dough and late dough stages of sweet corn show larger losses in respiration than the milk and early dough stages. The loss of respiration in the dough stage may very probably be explained by the loss of sugar but the late dough stage corn with 49 percent moisture stored at 30° showed a loss of 52 percent in respiration which seemingly can not be explained by the loss of sugars. Determinations of the free and bound water will prove to be important in explaining these differences in the respiratory activity of corn kernels when the total moisture has been reduced.

With sweet corn the respiration loss for corn stored at 30° was always several times greater than the loss when the corn was stored at 5°C. The loss of sugars was usually 2 to 3 times as much in the warm stored as in the cold stored. In general, the effect of storage of milk and early dough stage corn in the 2 years' experiments at 30° caused an actual average decrease of 34 percent in total sugars, in contrast to the average 6 percent loss in respiration and 29 percent loss in total sugars when the corn was stored at 5°.

The figures in the parentheses in table 13 show the differences in the percentage losses of respiration and sugars of corn in the same stage of ripening stored at the two temperatures. It is interesting to note that the differences for the respiration data agree very closely with the sugar differences except with corn in the late dough stage. The significance of these data and the actual differences of the total sugar and respiration losses in the milk and early dough sweet corn may be better

Table 13 --Percent losses of the oxygen respiration and sugars when Stowell's Evergreen corn is stored at 5° and 30° C. for four days. The values in parentheses are the differences in the percentage losses between the analyses of corn stored at 30° and at 5°C.

1936 Experiment						
Stage of ripening	Storage	Decrease in respiration	Decrease in total sugar	Decrease in reducing sugar	Decrease in sucrose	
	Deg. C.	Percent	Percent	Percent	Percent	
Milk	30	39.0	60.2	54.6	62.9	
	5	4.7 (34.3)	26.9 (33.3)	23.6 (31.0)	28.5 (34.4)	
Early dough	30	38.8	60.9	34.0	71.6	
	5	13.4 (25.4)	35.6 (25.3)	7.2 (26.8)	47.0 (24.6)	
Dough	30	47.0	64.0	39.5	75.6	
	5	4.0 (43.0)	14.5 (49.5)	15.8 (23.7)	13.5 (62.1)	
Late dough	30	52.2	28.4	19.8	34.0	
	5	0.0 (52.2)	9.1 (19.3)	11.8 (8.0)	7.7 (26.3)	
1937 Experiment						
Milk	30	21.0	53.9	52.8	54.9	
	5	3.2 (17.8)	25.9 (28.0)	6.1 (46.7)	33.6 (21.3)	
Early Dough	30	36.4	55.7	13.3	78.8	
	5	3.5 (32.9)	27.0 (28.7)	27.6	26.7 (52.1)	



understood by referring to figure 11.

The data as presented in figure 11 indicate that there is no parallelism between the rate of sugar loss and the rate of loss of respiration in the corn after warm and cold storage. This does not exclude the possibility of an existing correlation between respiration and total sugar within these two points of analysis. The data in figure 11 seem to indicate that there is a parallelism after the respiration and total sugar values have decreased to the values observed for the corn after cold storage.

By extrapolation to the point where there is no loss of respiration it is seen that a 21 to 22 percent loss of sugar may occur before an influence is shown on the respiration. It may be that a correlation between respiration and sugar may exist after the sugar content has been lowered to this point.

Experiment 3. For this experiment 15 ears of milk stage Stowell's Evergreen corn were carefully selected. The corn was divided into 5 lots of 3 ears each. All of the lots were stored in an insulated box in which a temperature of  $30^{\circ} \pm 0.2$  was maintained. All of the ears were wrapped in paraffined paper to prevent excessive loss of moisture. Holes were made in the paper to provide for aeration. The moisture content in the 5 lots varied from 81.2 to 83.4 percent.

On the morning that the corn was picked samples were removed from each of the 3 ears in Lot 1 and analyses and respiratory tests made. A second sample was removed from the same lot 12 hours after the first sample, and a third sample 12 hours after the second, so that the changes were followed at 12 hour intervals. At the time that the third sample was removed from lot 1, the first sample was removed from lot 2. The sampling was continued at 12 hour intervals until the 5 lots had been used.

Stowell's Evergreen Corn

Percentage Loss

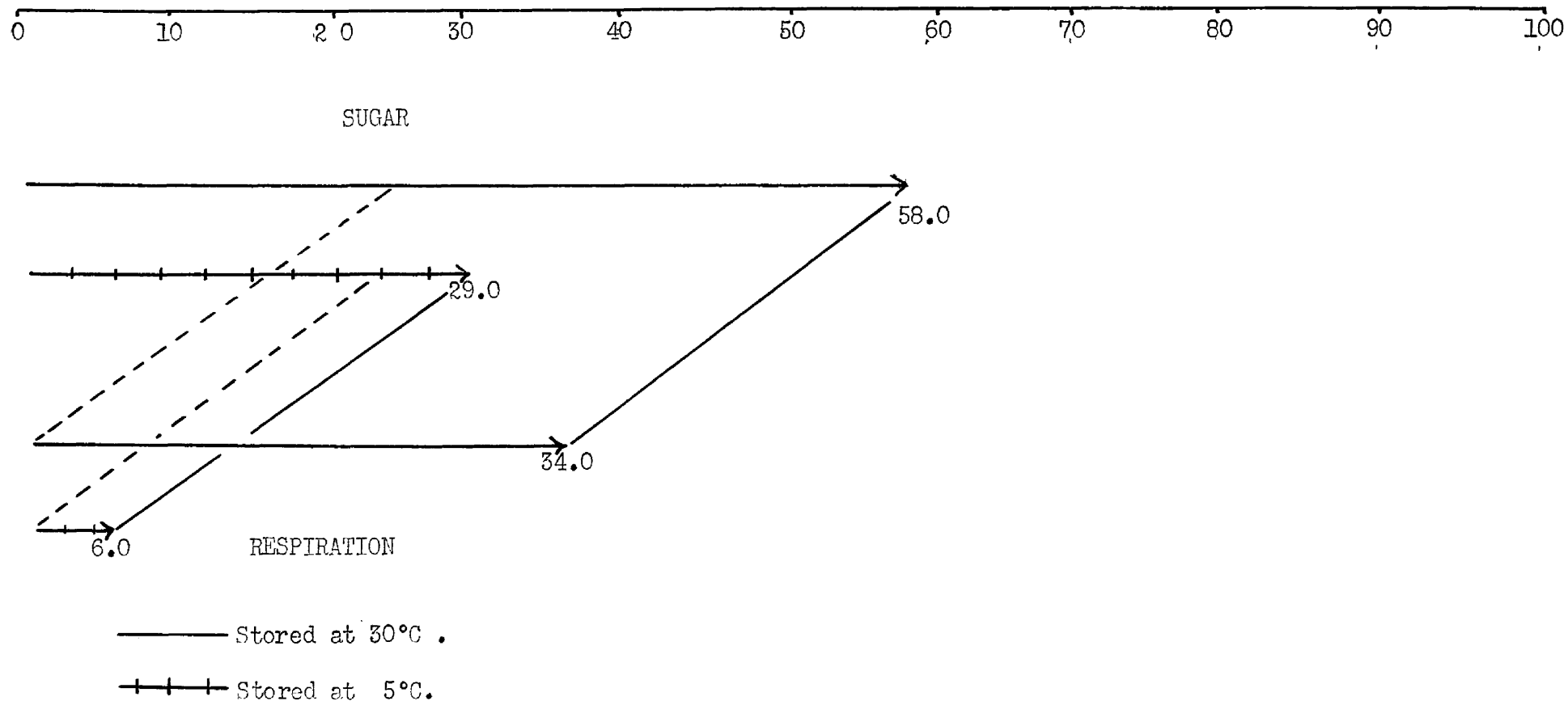


Fig. 11. The percentage losses of the respiration and total sugar in Stowell's Evergreen corn after 4 days' storage at 5° and 30°C. The average values of the two experiments with the milk and early dough stage corn have been used.

The respiration samples consisted of 30 kernels in each of the duplicate determinations. Twenty kernels were removed from each ear, 10 of which were placed in one respirometer and 10 in another.

The changes that occurred in the oxygen respiration, weight of kernels, and sugar content of the sweet corn when stored at 30°C. for 120 hours are given in table 14. The respiration and sugar changes are presented graphically in figure 12.

The difference in respiration between the first and second samples tested on the first day may probably be explained by the fact that the first samples were more mature. The weights of the respiration samples seem to indicate this fact since the second sample weighed considerably less than the first sample.

The general trend of the curves indicates a rapid loss of sugars and of respiration in the first 24 hours of storage. The loss of respiration is not as great as the loss of sugars, if the respiration rate of the first sample of the first day is considered as the reference.

The respiration curve parallels the three sugar curves rather closely after the first day except for the last day when the respiration curve still fell. The sugar concentrations after the fourth day remained nearly constant.

Experiment 4. The problem of the effect of storage of kernels off and on the cob on the respiration and sugar content with Stowell's Evergreen corn in the milk and dough stages was investigated. The material used was the same corn used for part of the work in experiment 2. Some of the data will thus appear in more than one place and is presented for the sake of comparison.

The 12 ears were divided into 2 lots of 6 ears each, one of which

Table 14.--The changes in the oxygen respiration, weight of kernels, and sugar content of green Stowell's Evergreen corn when stored at 30°C. for 120 hours.

Storage at 30°C.	Average weight of 30 kernels	O <sub>2</sub> consumed per gram in first 15 minutes	Total Sugar	Reducing Sugar	Sucrose
Hours	Grams	Cmm	Percent	Percent	Percent
0	7.47	101.0	7.12	2.71	4.10
12	6.60	124.5	5.11	1.98	2.90
24	7.80	91.8	4.17	1.86	2.13
24	7.07	95.7	4.11	1.79	2.14
36	6.79	89.3	3.68	1.49	2.02
48	6.61	83.0	3.23	1.34	1.74
48	7.08	80.5	3.55	1.76	1.64
60	7.12	81.8	3.11	1.47	1.50
72	6.80	79.8	3.00	1.45	1.41
72	7.69	76.0	2.21	1.05	1.05
84	7.43	68.9	2.05	0.93	1.03
96	7.72	66.3	1.83	0.95	0.79
96	7.20	62.4	1.93	1.05	0.80
108	7.65	59.4	1.66	0.79	0.80
120	7.62	57.0	1.62	0.79	0.75

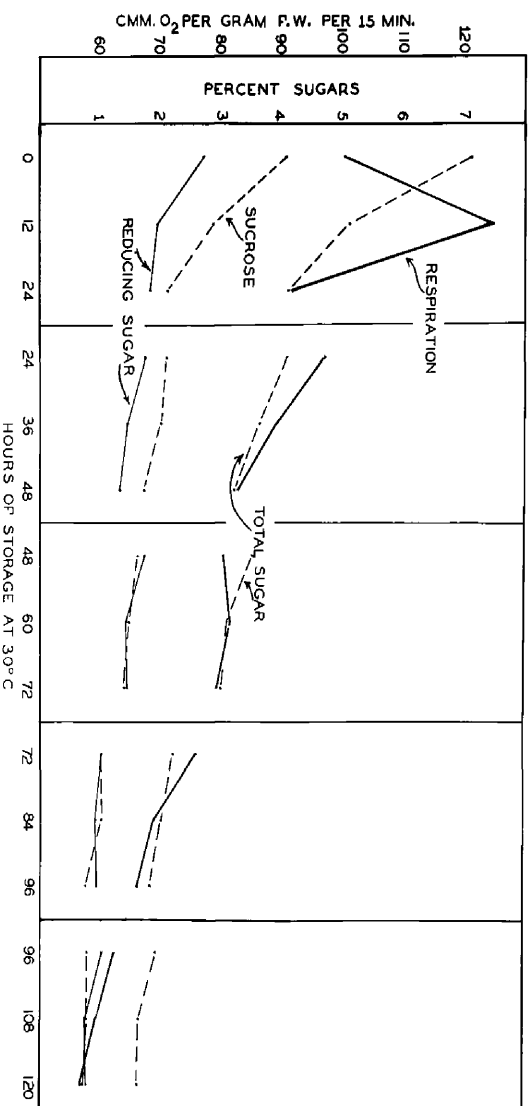


Fig. 12. Changes in the oxygen respiration at 50°C. and sugars when Green Stowell's Evergreen corn is stored at 50°C. for 120 hours.

was stored at 5° and another at 30°C. Ten kernels were removed from each of the ears of the lot to be stored at 30°C., 5 of which were placed in one respirometer and 5 in another. Readings were taken after the samples had been in the respirometer from 30 minutes and after 9 to 10 hours. Samples for the moisture and sugar determinations were taken 2 hours after picking. At the time the respiration samples were removed from the lot to be stored at 30°C. another sample which consisted of 3 rows of kernels from each ear were removed and stored at 30°C. in a jar containing a vial of potassium hydroxide. This sample was stored so as to duplicate the storage conditions of the samples in the respirometers. After 9 to 10 hours storage these samples were removed for determinations of sugar and moisture.

After the 6 ears had been stored at 30°C. for 12 to 13 hours, samples were again removed for respiration, sugar, and moisture determinations. These data are for the kernels stored on the cob.

After 4 days of storage the lot stored at 5°C. was removed and respiration, sugar, and moisture samples taken. The respiration samples were tested 30 minutes after they had been in the respirometers and again after 11 to 12 hours. At the same time the respiration samples were removed another sample of 3 rows of kernels from each ear was removed and placed in a jar with a vial of potassium hydroxide. The jar was placed in a water bath at 30°C. After 11 to 12 hours the kernels were removed and samples taken for moisture and sugar determinations. These samples were comparable to those kernels stored off the cob which were left in the respirometers for the same period.

After the samples had been removed from the 5°C. stored lot, the ears

were wrapped and stored at 30°C. for 14 to 15 hours. After this period of storage, samples were taken of the kernels stored on the cob. The average moisture content of the milk stage corn kernels before storage was 79.2 percent, after storage on the cob 78.6, and after storage off the cob 79.1 percent. For the dough stage corn the average values for the moisture of kernels before storage was 71.1, after storage on the cob 70.5, and after storage off the cob 70.7 percent. The results of the respiration and sugar changes are presented in table 15.

In every case the kernels stored on the cob at 30°C. always showed a higher respiration rate and a higher total sugar and sucrose content than kernels that were removed from the ears and stored under the same conditions. In three of the four experiments the kernels stored off the cob had a higher reducing sugar content than the kernels stored on the cob. In the fourth case there was a difference of .09 percent sugar. This general trend indicates that the reducing sugar content may be increased at the expense of the sucrose and other sugars and as a result a decrease in the respiration. These general data show that the respiration in immature corn kernels is related more closely to the total sugar than to the reducing sugar.

It is to be pointed out that after the milk stage corn was picked there was a 23 percent loss of total sugars and a 9 percent loss in respiration in the kernels stored on the cob. In the dough stage corn there was a 33 percent loss of total sugars and a 5 percent loss in respiration. These data indicate that sweet corn in the milk and dough stages shows a considerably greater rate of loss of total sugars than rate of loss of respiration.

Table 15--The effect of storage of kernels on and off the cob at 30° C. on the oxygen respiration at 30° C. and sugar content in Stowell's Evergreen corn in the milk and dough stages.

Milk Stage					
Original lot after picking					
Storage conditions:	Treatment: Time	O <sub>2</sub> per gram:	Total sugar	Sucrose	Reducing sugar
	: hours	: cmm	: per cent	: percent	: percent
Original lot	—	107.1	7.39	4.86	2.27
K. on cob:	12	97.3	5.69	3.81	1.68
K.off cob:	10	84.5	5.37	3.26	1.94
Original lot after 4 days at 5°C.					
Original lot	—	102.7	4.66	2.84	1.67
K. on cob:	14	90.8	3.79	2.37	1.30
K.off cob:	11	76.3	3.19	1.98	1.21
Dough Stage					
Original lot after picking					
Original lot	—	75.7	4.68	2.88	1.65
K. on cob:	13	72.3	3.14	2.04	0.99
K.off cob:	9	63.9	3.12	1.65	1.38
Original lot after 4 days at 5° C.					
Original lot	—	73.9	3.11	2.03	0.97
K. on cob:	15	66.3	2.89	1.27	1.55
K.off cob:	12	51.0	2.49	0.79	1.66



## Field Corn

Experiment 1.--In the 1936 study the 6 ears of Reid's Yellow Dent corn used in the first two tests in the study of the relation of respiration to sugar and moisture content at different stages of ripening were divided into 2 lots of 3 ears each. One lot was stored at 30° and the other at 5°C for 4 days. After the storage period analyses and tests were again made. In the 1936 study a sugar analysis was made 2 hours after picking on the entire lot of 6 ears before storage, and then a similar analysis on each of the 2 lots after the storage period.

The 10 kernel respiration samples taken from each ear varied from 2.1 to 3.3 grams for kernels in the milk stage and 3.4 to 4.8 grams for dough stage samples. The average values for the respiration of the samples are given in table 16. The sugar and moisture changes for the same samples are given in table 17. The combined data are presented graphically in figure 13.

Experiment 2.--The effect of storage at 5° and 30°C. on the oxygen respiration and sugar content of Reid's Yellow Dent corn was repeated in the 1937 season. The material used in the two years was grown on the same plot.

The 12 ears of corn used for the first 2 tests in the study on the changes during the ripening period were divided into 2 lots of 6 ears each. One lot was stored at 5°C. and the other at 30°C. for 4 days. At the end of the storage period analyses and tests were again made. The 1937 procedure differed from that used in 1936 in that a sugar analysis was made on each of the 2 lots previous to storing, 2 hours after they were picked. The selection of respiration samples also differed from the method used in 1936. Ten kernels of the grain were removed from each ear,

Table 16.—Effect of storage at 5° and 30°C. on the oxygen respiration at 30°C. of Reid's Yellow Dent corn at different stages of ripening.

Stage of ripening:	Treatment	O <sub>2</sub> per hour per gram fresh weight for hour period indicated					
		1	2	3	4	5	6
		Cmm	Cmm	Cmm	Cmm	Cmm	Cmm
Milk	Two hours after picking on Aug. 20	341.3	339.7	336.5	328.5	312.3	299.9
	After 4 days storage at 5°C.	304.0	306.0	310.0	306.9	289.8	279.1
	Two hours after picking on Aug. 20	333.5	326.9	317.4	304.7	286.3	273.9
	After 4 days storage at 30°C.	151.0	150.6	148.2	146.6	142.1	141.1
	Two hours after picking on Sept. 8	242.9	244.3	238.1	228.5	219.6	206.2
	After 4 days storage at 5°C.	220.7	225.3	220.3	-----	-----	179.9
Late Dough	Two hours after picking on Sept. 8	240.1	241.0	236.9	227.3	217.3	206.6
	After 4 days storage at 30°C.	117.9	118.9	116.9	-----	-----	111.0

Table 17 .--The moisture and sugar content of Reid's Yellow Dent corn used for the respiration tests given in table 16 . 1936 Study.

Stage of ripening:	Treatment	Moisture	Total Sugar	Reducing Sugar	Sucrose
		Percent	Percent	Percent	Percent
	Two hours after picking on Aug.20	73.17	4.57	1.80	2.63
Milk	After 4 days storage at 5°C.	73.04	3.15	1.40	1.66
	After 4 days storage at 30°C.	71.06	0.83	0.50	0.31
	Two hours after picking on Sept.8	56.84	2.88	1.03	1.76
Late Dough	After 4 days storage at 5°C.	54.41	1.85	0.76	1.04
	After 4 days storage at 30°C.	52.98	0.85	0.42	0.41

Table 18 .---Effect of storage at 5° and 30°C. on the oxygen respiration at 30°C. of Reid's Yellow Dent corn at different stages of ripening.

Stage of ripening:	O <sub>2</sub> :per hour per gram fresh:weight for hour period indicated					
	1	2	3	4	5	6
	Cmm	Cmm	Cmm	Cmm	Cmm	Cmm
Milk						
:Two hours after pick- :ing on Aug. 13	: 333.9	: 332.7	: 322.2	: 327.3	: 305.9	: 283.5
:After 4 days storage : at 5°C.	: 309.1	: 312.9	: 313.2	: 306.9	: 289.8	: 275.0
:Two hours after pick- :ing on Aug. 13	: 294.3	: 290.6	: 286.5	: 291.7	: 271.6	: 247.8
:After 4 days storage : at 30°C.	: 146.4	: 149.7	: 149.8	: 147.6	: 140.9	: 140.1
Late Dough						
:Two hours after pick- :ing on Aug. 27	: 207.9	: 191.8	: 197.1	: 192.3	: 195.0	: 184.3
:After 4 days storage : at 5°C.	: 197.8	: 188.3	: 189.8	: -----	: -----	: 177.0
:Two hours after pick- :ing on Aug. 27	: 204.0	: 190.9	: 202.5	: 200.8	: 199.4	: 189.7
:After 4 days storage : at 30°C.	: 104.5	: 104.1	: 102.7	: -----	: -----	: 98.7

Table 19.—The moisture and sugar content of Reid's Yellow Dent corn used for the respiration tests given in table . 1937 Study.

Stage of ripening:	Treatment	:Moisture :	Total :	Reducing :	Sucrose :
		:Percent :	Percent:	Percent :	Percent :
Milk	:Two hours after picking on Aug. 13	: 75.09	: 4.95	: 1.95	: 2.85
	:After 4 days storage at 5°C.	: 74.27	: 4.00	: 1.81	: 2.08
	:Two hours after picking on Aug. 13	: 70.00	: 3.78	: 1.43	: 2.23
	:After 4 days storage at 30°C.	: 67.67	: 1.25	: 0.82	: 0.41
	:Two hours after picking on Aug. 27	: 57.85	: 2.28	: 0.92	: 1.29
	:After 4 days storage at 5°C.	: 57.92	: 1.67	: 0.84	: 0.79
Late Dough	:Two hours after picking on Aug. 27	: 56.81	: 2.09	: 0.94	: 1.09
	:After 4 days storage at 30°C.	: 52.81	: 0.88	: 0.47	: 0.39

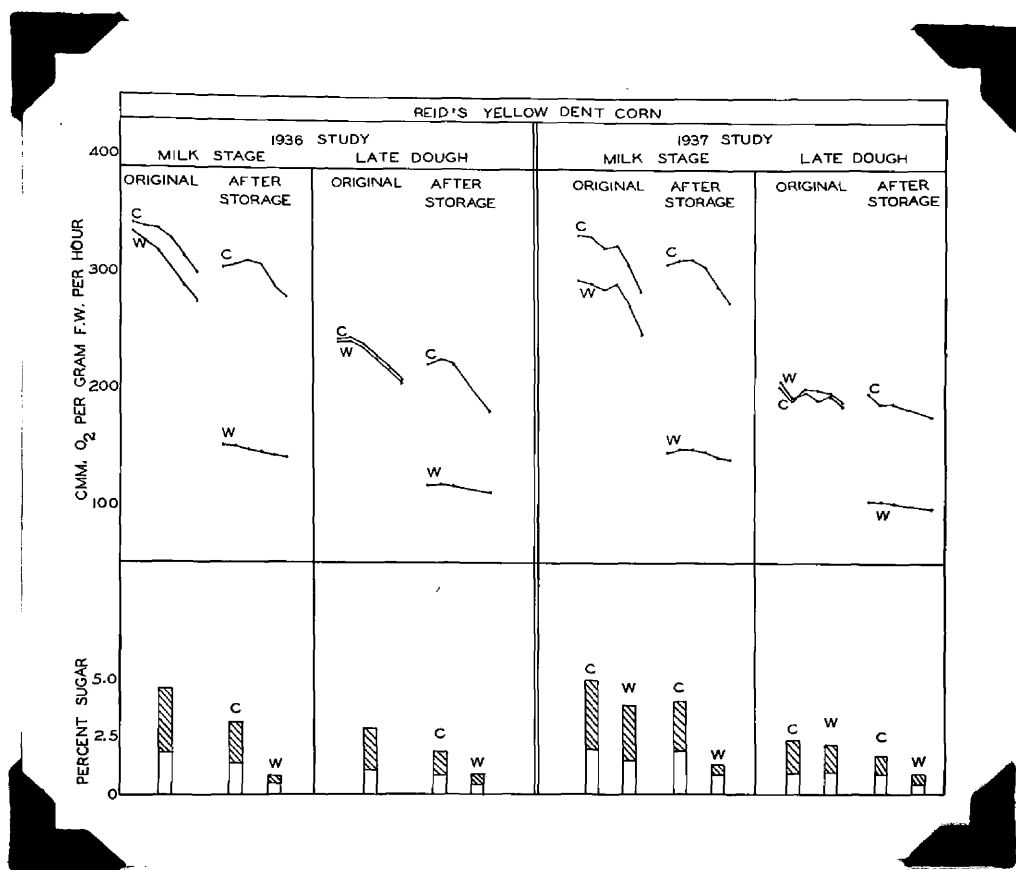


Fig. 13. Effect of warm (30°C.) and cold (5°C.) storage on the oxygen respiration at 30°C. and sugar content of Reid's Yellow Dent corn. The height of the columns indicates total sugars and the open portions reducing sugars. C--cold stored for four days; W--Warm stored for four days.

5 of which were placed in one respirometer and 5 in another. The 30 kernel respiration samples varied in weight from 9.1 to 10.2 grams for milk stage kernels and from 13.2 to 14.5 grams for dough stage kernels. The respiration data which are the average of duplicate determinations are given in table 18. Table 19 shows the sugar and moisture content of the same samples. The combined data are presented graphically in figure 13.

In table 20 are calculated the percentage losses of the respiration and sugars when field corn in the milk and dough stages is stored at 5° and 30°C. The corn in the two stages showed the same general trends. The respiration loss for corn stored at 30° was always 5 to 9 times greater than the loss shown by the corn stored at 5° C. The losses of the sugars in the warm stored was about 2 to 3 times greater than the losses of the cold stored corn. In general the effect of storage at 30°C. for 4 days caused an actual decrease of an average 51 percent in the respiration, while an average 7 percent loss occurred when corn was stored at 5°C. The actual percentage decrease of sugars was usually considerably greater than the decrease in respiration.

The figures in parentheses in table 20 show the differences in the percentage decreases of respiration and sugars in corn in the same stage of ripening stored at the two temperatures. It is interesting to note that the differences of the respiration and of the sugars agree rather well. The significance of this and the actual differences of the total sugar and respiration losses when the corn is stored at the two temperatures may be gained from figure 14. The data seem to indicate that there is no parallelism between the rate of sugar loss and the rate of loss of respiration in the corn when analyzed after cold and warm storage, but this does not

Table 20—Percent losses of oxygen respiration and sugars when Reid's Yellow Dent corn is stored at 5° and 30° C. for four days.

1936 Experiment					
Stage of ripening	Storage : Deg. C	Decrease in : respiration : Percent	Decrease in : total sugar : Percent	Decrease in : reducing sugar : Percent	Decrease in : sucrose : Percent
Milk	30	54.7	81.8	72.2	88.2
	5	9.2	31.0	22.2	36.8
		(45.5)	(50.8)	(50.0)	(51.4)
Late dough	30	50.6	70.5	59.2	76.7
	5	7.8	35.7	26.2	40.9
		42.8	(34.8)	(33.0)	(35.8)
1937 Experiment					
Milk	30	49.0	66.9	42.6	81.6
	5	7.4	19.1	7.2	23.3
		(41.6)	(47.8)	(35.4)	(58.3)
Late dough	30	48.7	57.8	50.0	64.2
	5	4.9	26.7	8.6	38.7
		(43.8)	(31.1)	(41.4)	(25.5)



Reid's Yellow Dent Corn

Percentage Loss

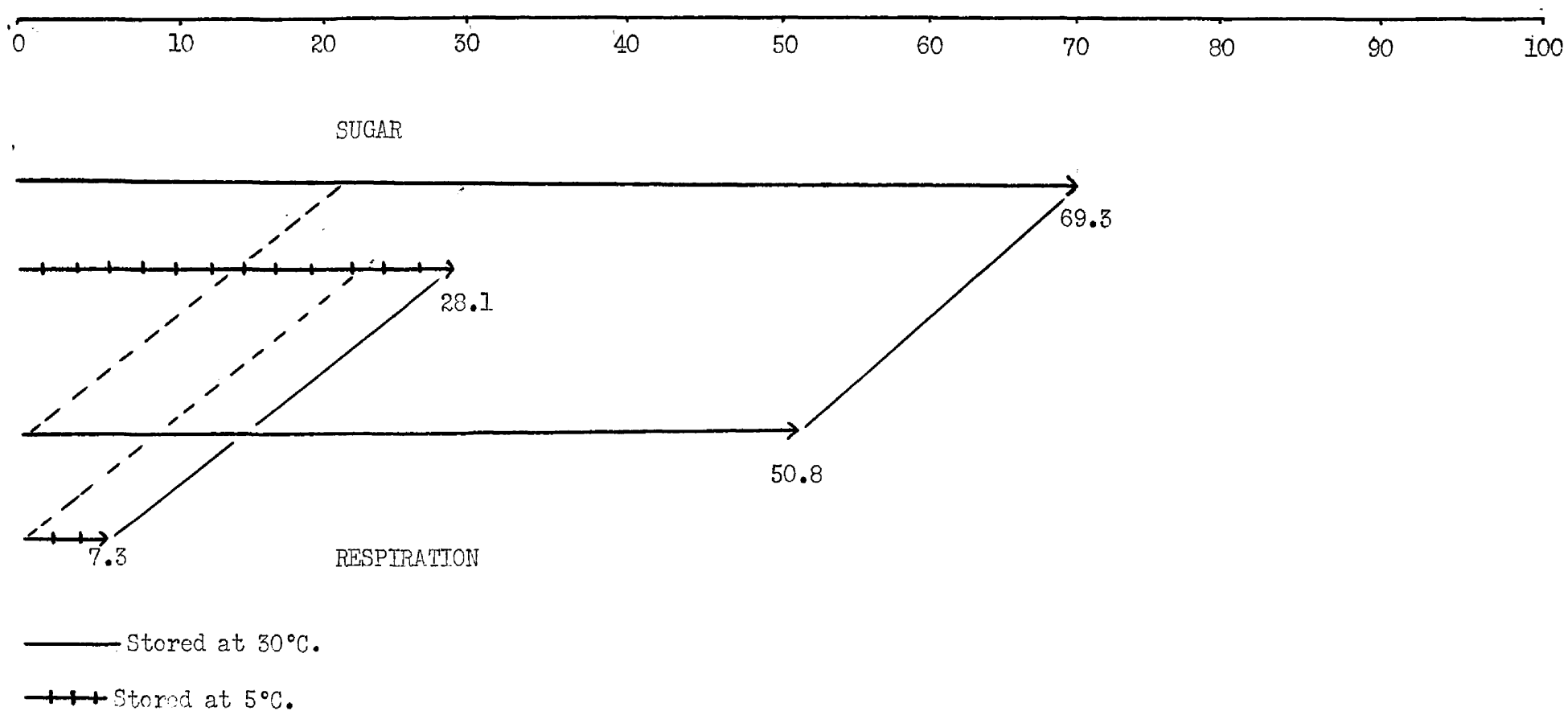


Fig. 14. The percentage losses of the respiration and total sugar in Reid's Yellow Dent corn after 4 days storage at 5° and 30°C. The average values of the two experiments with the milk and early dough stage corn have been used.

exclude the possibility of a correlation between the two within the two points of analysis. The presentation of the data in figure 14 does seem to indicate such a correlation after the respiration and sugar values have decreased to the values observed after the period of cold storage. If the extrapolation of the respiration curve is made until there is zero loss a value of 20 percent sugar is obtained. This again may indicate that a 20 percent loss in sugar may occur before the respiration is effected, and that the parallelism between sugar and respiration may continue from this point. It is rather interesting that the extrapolated values of sugar content where no loss is shown in the respiration is about 20 to 22percent for both the field and sweet corn.

## SUMMARY

The Warburg manometer and constant volume type of respirometer was used as a means to measure the oxygen consumption in some actively respiring plant materials. It was shown that care must be exercised to insure an adequate supply of oxygen in the respirometer when time rate of respiration curves are studied. The critical oxygen tension for the respiration of immature kernels of Stowell's Evergreen and Reid's Yellow Dent corn was found to be 15 to 16 percent oxygen.

The relation between the oxygen respiration and moisture and also sugar content was studied in the two varieties when in the milk stage and continued throughout the ripening period. The respiration curve paralleled the moisture curve in the sweet corn after the moisture had been reduced to 70 percent. When the corn contained more than this amount there was a crossing of the curves. In the field corn the curves paralleled throughout the entire study. The total sugars and sucrose were found to parallel the respiration curve more closely than did the reducing sugar.

The time rate of respiration curves were studied for 10 hours for immature wheat kernels at different stages of ripening. The time rate curves were not constant but decreased for the milk stage kernels with 61 percent moisture and continued to do so until the moisture content was reduced to 30 percent. The respiration and moisture curves crossed when the kernels had 40 to 45 percent moisture. The sugars were not correlated with the respiration.

The effect of storage of the green sweet and field corn at 5° and 30° on the respiration and sugar content was studied. It was found that

the loss of sugars from milk and early dough stage sweet corn stored at 30° was 2 times that lost from corn stored at 5°C. The respiration loss for corn stored at 30° was about 6 times that loss shown by corn stored at 5°C. The sugar losses of field corn stored at 30° was 2.5 times as great as that lost when stored at 5°, while the respiration loss of corn stored at 30° was 7 times that lost when stored at 5°. The possibility of an existing parallelism between respiration and sugar is discussed.

The changes in respiration and sugar content were studied in sweet corn at 12 hour intervals when the corn was stored at 30°C. for 120 hours. The respiration curve paralleled the sugar curves except for the first and fifth days of storage.

The effect of storage of sweet corn kernels off and on the cob at 30°C. on the respiration and sugar changes was studied. Kernels stored off the cob always had a lower respiration rate, lower total sugars and sucrose, but the same amount or more of reducing sugar than similar kernels stored on the cob. The respiration in all of the corn studied seemed to be more closely correlated with the total sugars and sucrose than with the reducing sugar.

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