

# Respiration and Weight Losses of Potatoes During Storage

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Potato tubers lose weight in the process of respiration, converting sugar and starches to carbon dioxide (CO<sub>2</sub>) and water and losing moisture because of vapor pressure differences between the tubers and the surrounding air. The purpose of this investigation was to examine the total weight loss and the part of it due to respiration as affected by variety, temperature and humidity in storage.

## Materials and Methods

The potato varieties Kennebec, Norgold Russet and Red Pontiac used in these studies were

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grown at the Red River Valley Potato Research Farm near Grand Forks, North Dakota, from 1966 to 1968. Tubers were dug with a small mechanical digger, hand picked from the ground and transported to Fargo. They were washed and weighed in air and water to determine the specific gravity of each tuber. Then, five tubers, weighing from 150 to 400 grams each, were placed in sealed one gallon glass jars.

The potato tubers were held at three temperatures, 40°F (1967), 50°F (1966), and 65°F (1968) and four relative humidities, 65, 81, 93, and 100 per cent. The 65, 81, and 93 per cent relative humidities were maintained with small plastic containers filled with a saturated salt solution. To achieve 100 per cent relative humidity, the con-

tainers were filled with distilled water. Jars containing the tubers had lids with connectors so that gas concentration (respiration) measurements could be made. Respiration measurements were made by measuring the increase in CO<sub>2</sub> and the decrease in oxygen (O<sub>2</sub>) over a known time period for each jar by injecting a sample of container gas into a Fisher Model 29 gas partitioner. Time between measurements was about three days.

After the gas analysis was made, the jars were purged to start with a zero CO<sub>2</sub> concentration. A chemical absorbant was used to remove any CO<sub>2</sub> from the fresh air that replaced the gases purged from the jars. The general procedure and method of calculation for determining the CO<sub>2</sub> production rate was developed by Moore (1).

A computer program was written to calculate the respiration rate and the respiratory quotient (RQ) of the tubers. Input into the program was CO<sub>2</sub> and O<sub>2</sub> concentration measurements, lapse of time between tests, weight of tubers, temperature, and barometric pressure. Output consisted of the rate of CO<sub>2</sub> production and O<sub>2</sub> consumption at each test time, respiratory quotient (RQ), the day of the test, and other information identifying the tubers. A computer program was also written to calculate the per cent weight loss of each tuber as a function of time.

Both the respiration rate and the weight loss data were then used in a regression analysis. The two computer programs used for the regression analysis were a Nebraska regression analysis program (2) and a step-wise multiple-linear regression analysis program (3). In the Nebraska regression analysis program the respiration rate was the dependent variable and days in storage, temperature, relative humidity, and tuber weight were the independent variables. In an analysis using the step-wise regression program, the dependent variables were both respiration rate and weight loss, and in addition to the independent variables used in the other programs, reducing sugar concentration, CO<sub>2</sub> concentration, specific gravity of the tuber and respiratory quotient (RQ) were added.

The weight loss of the tubers was partitioned into the portion due to respiration and that due to vapor pressure differences (VPD). This was accomplished by first calculating the linear regression line for per cent weight loss vs. time in days. This gave the total per cent weight loss. Then the apparent respiration rate, measured as CO<sub>2</sub> production, was calculated and the regression of the rate of CO<sub>2</sub> production vs. time was determined. The equation of this line was then integrated to obtain the cumulative weight loss due to the CO<sub>2</sub> losses

from the tuber. The total respiration losses were determined by multiplying the total cumulative CO<sub>2</sub> losses by a constant of 32/22 or the ratio of CO<sub>2</sub> plus water vapor over CO<sub>2</sub> molecular weight. This is based upon the assumption that in the metabolic processes primarily glucose is utilized and the standard chemical equation would therefore apply.

## RESULTS

Analysis of CO<sub>2</sub> production of Kennebec tubers using the Nebraska regression program are tabulated in Table 1. Kennebecs only were used in this analysis since it was the variety under major consideration in this series of tests. The relative humidity-squared and temperature-squared variables were the best single predictors of the CO<sub>2</sub> production rate, and were followed by day-squared and potato weight-squared of the form variables examined. When the variables are combined for a multiple regression analysis, the linear form of day plus relative humidity plus temperature plus potato weight gave a slightly better prediction of CO<sub>2</sub> production than the squares of these variables. The improvement in the prediction of the CO<sub>2</sub> production was increased by considering both the linear and quadratic forms of the independent variables.

**Table 1. Summary of regression analysis of carbon dioxide production rate versus various independent variables.**

Variable	Regression Coefficient	R <sup>2</sup>	Standard Error	F
DAY-SQ	0.7636 × 10 <sup>-9</sup>	0.0150	0.00008	7.29
RH-SQ	0.5401 × 10 <sup>-8</sup>	0.2817	0.00007	188.25
TEMP-SQ	0.1123 × 10 <sup>-7</sup>	0.1439	0.00007	80.70
POTWT-SQ	0.2072 × 10 <sup>-11</sup>	0.0079	0.00008	3.83
DAY	-0.1689 × 10 <sup>-9</sup>	0.3544	0.00006	65.47
RH	0.1330 × 10 <sup>-5</sup>			
TEMP	-0.1354 × 10 <sup>-5</sup>	0.3141	0.00007	54.60
POTWT	0.4857 × 10 <sup>-8</sup>			
DAY-SQ	-0.6725 × 10 <sup>-9</sup>	0.6591	0.00005	114.32
RH-SQ	0.8830 × 10 <sup>-8</sup>			
TEMP-SQ	-0.1091 × 10 <sup>-7</sup>	0.3192 × 10 <sup>-8</sup>	0.00005	114.32
POTWT-SQ	0.1679 × 10 <sup>-11</sup>			
DAY	-0.3192 × 10 <sup>-8</sup>	0.6071 × 10 <sup>-5</sup>	0.00005	114.32
DAY-SQ	0.2491 × 10 <sup>-9</sup>			
RH	0.6071 × 10 <sup>-5</sup>	-0.4042 × 10 <sup>-7</sup>	0.00005	114.32
RH-SQ	-0.4042 × 10 <sup>-7</sup>			
TEMP	0.1250 × 10 <sup>-5</sup>	-0.1129 × 10 <sup>-8</sup>	0.00005	114.32
TEMP-SQ	-0.1129 × 10 <sup>-8</sup>			
POTWT	0.1540 × 10 <sup>-8</sup>	-0.2725 × 10 <sup>-10</sup>	0.00005	114.32
POTWT-SQ	-0.2725 × 10 <sup>-10</sup>			

DAY equals storage time in days  
RH equals per cent relative humidity  
TEMP equals temperature, °F  
POTWT equals tuber weight, grams

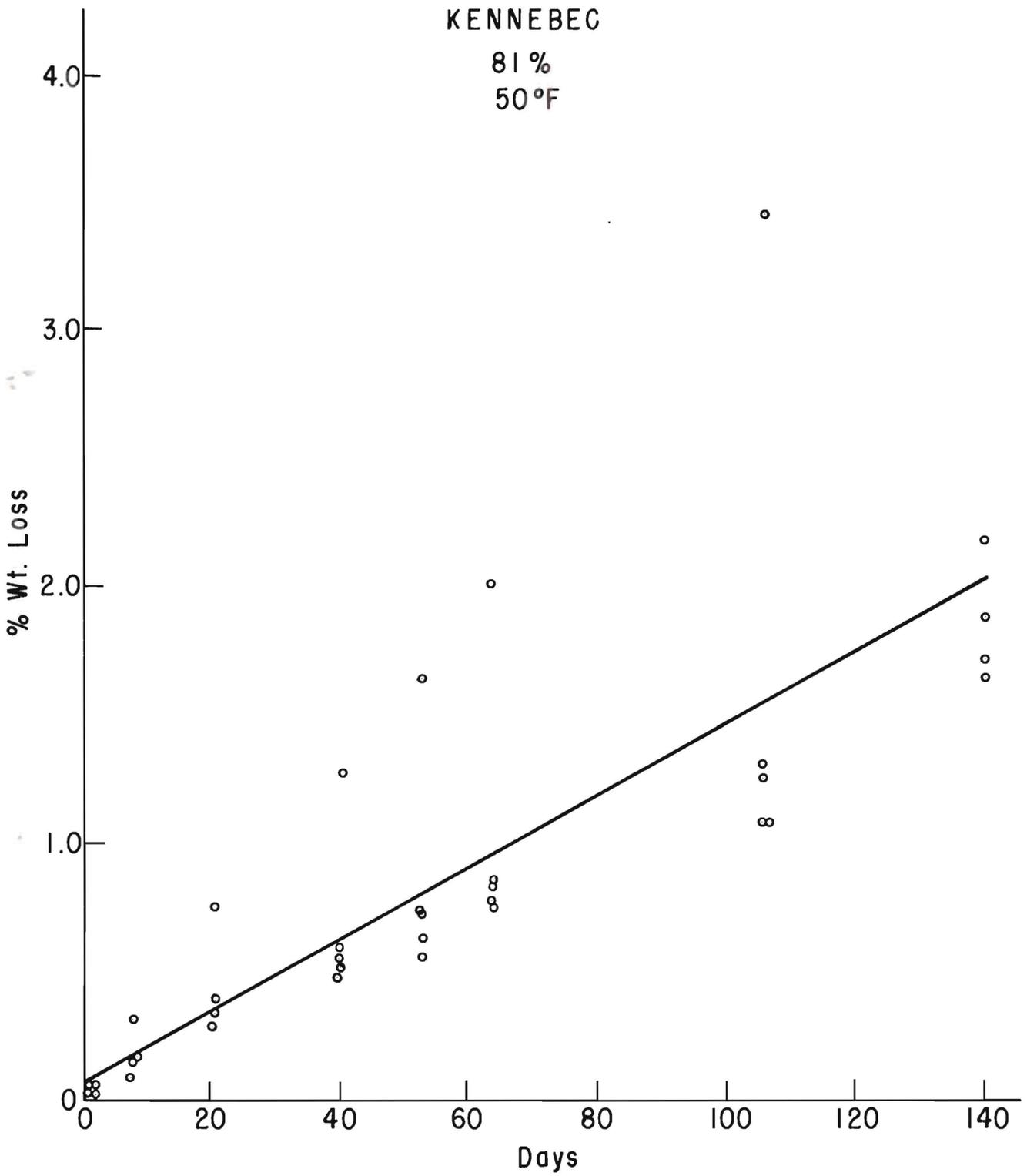


Figure 1. Per cent weight loss versus storage time in days for Kennebec tubers stored at 50°F, 81% relative humidity.

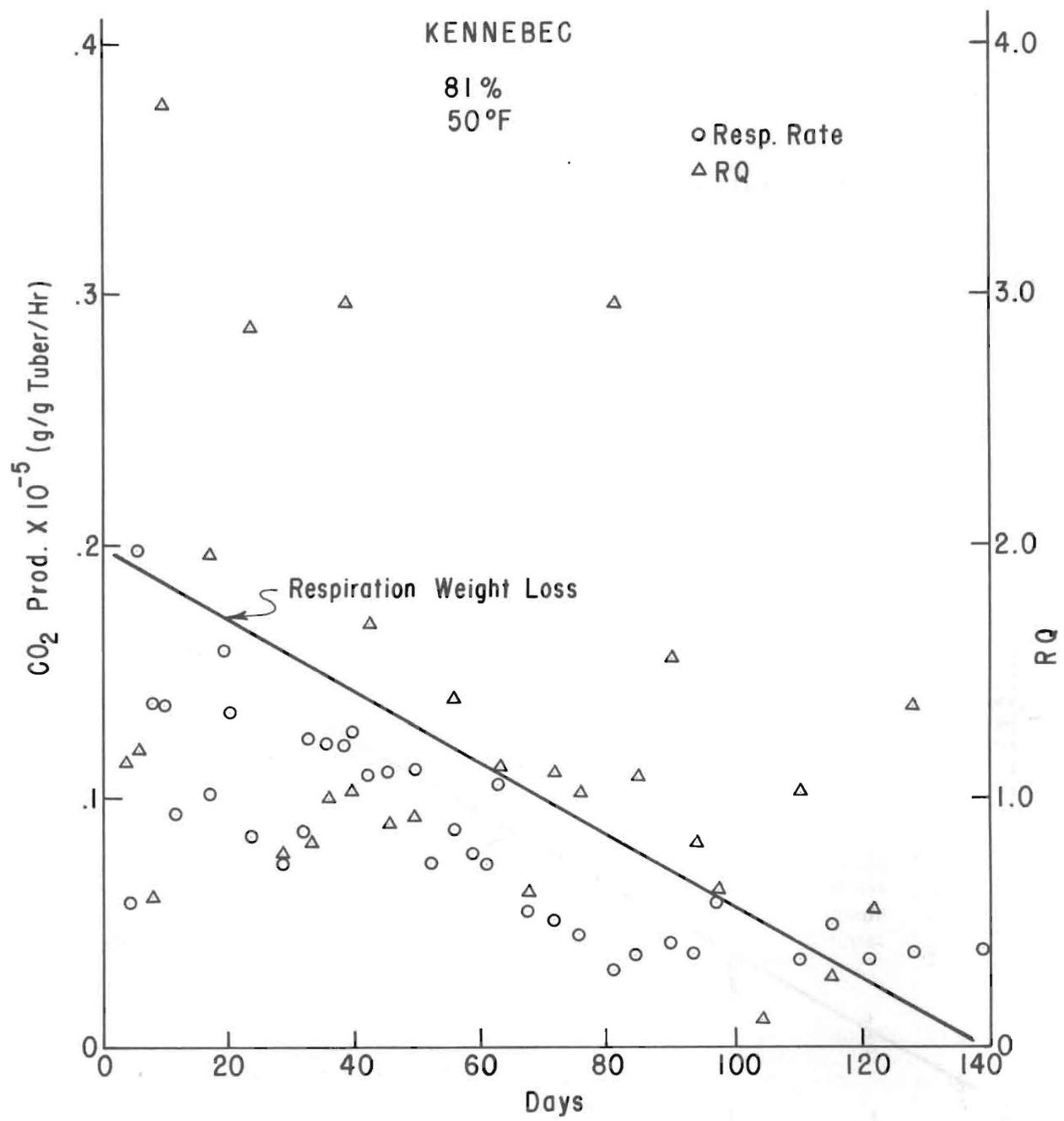


Figure 2. Carbon dioxide production rate, total respiration loss rate, and respiratory quotient (RQ) versus storage time in days for Kennebec tubers stored at 50°F, 81% relative humidity.

The equations for predicting the respiration rates for tubers of the three varieties, based upon the step-wise regression analysis, were:

**Kennebec**

$$\text{CO}_2 = 0.642416 \text{ E-03} + 0.12054 \text{ E-05 (RQ)} - 0.27847 \text{ E-06 (day)} - 0.90053 \text{ E-05 (temp)} + 0.11375 \text{ E-05 (SG)}^2 - 0.39991 \text{ E-05 (RH)} + 0.21982 \text{ E-07 (RH)}^2$$

**Norgold Russet**

$$\text{CO}_2 = 0.24407 \text{ E-02} - 0.23603 \text{ E-03 (temp)} + 0.23639 \text{ E-05 (temp)}^2 + 0.82916 \text{ E-04 (RH)} - 0.47985 \text{ E-06 (RH)}^2 - 0.12019 \text{ E-007 (day)}^2 + 0.14580 \text{ E-05 (day)} - 0.52746 \text{ E-06 (PWT)} + 0.10624 \text{ E-09 (PWT)}^2$$

**Red Pontiac**

$$\text{CO}_2 = 0.91382 \text{ E-03} + 0.13436 \text{ E-04 (RQ)} - 0.29558 \text{ E-05 (RH)} - 0.18867 \text{ E-04 (temp)} - 0.35688 \text{ E-06 (day)} + 0.13030 \text{ E-06 (TEMP)}^2$$

where:

- CO<sub>2</sub> = carbon dioxide production rate, g/hr/g tuber
- RQ = respiratory quotient
- day = storage time, days
- temp = storage temperature, F
- SG = specific gravity of tubers
- RH = relative humidity, per cent
- PWT = tuber weight, grams
- Redsug = reducing sugar concentration, g/100 g tuber

The R<sup>2</sup> values were 0.6056, 0.6724, and 0.6918 for the Kennebec, Norgold Russet and Red Pontiac tubers, respectively. The F-values were 121, 43 and 85, respectively.

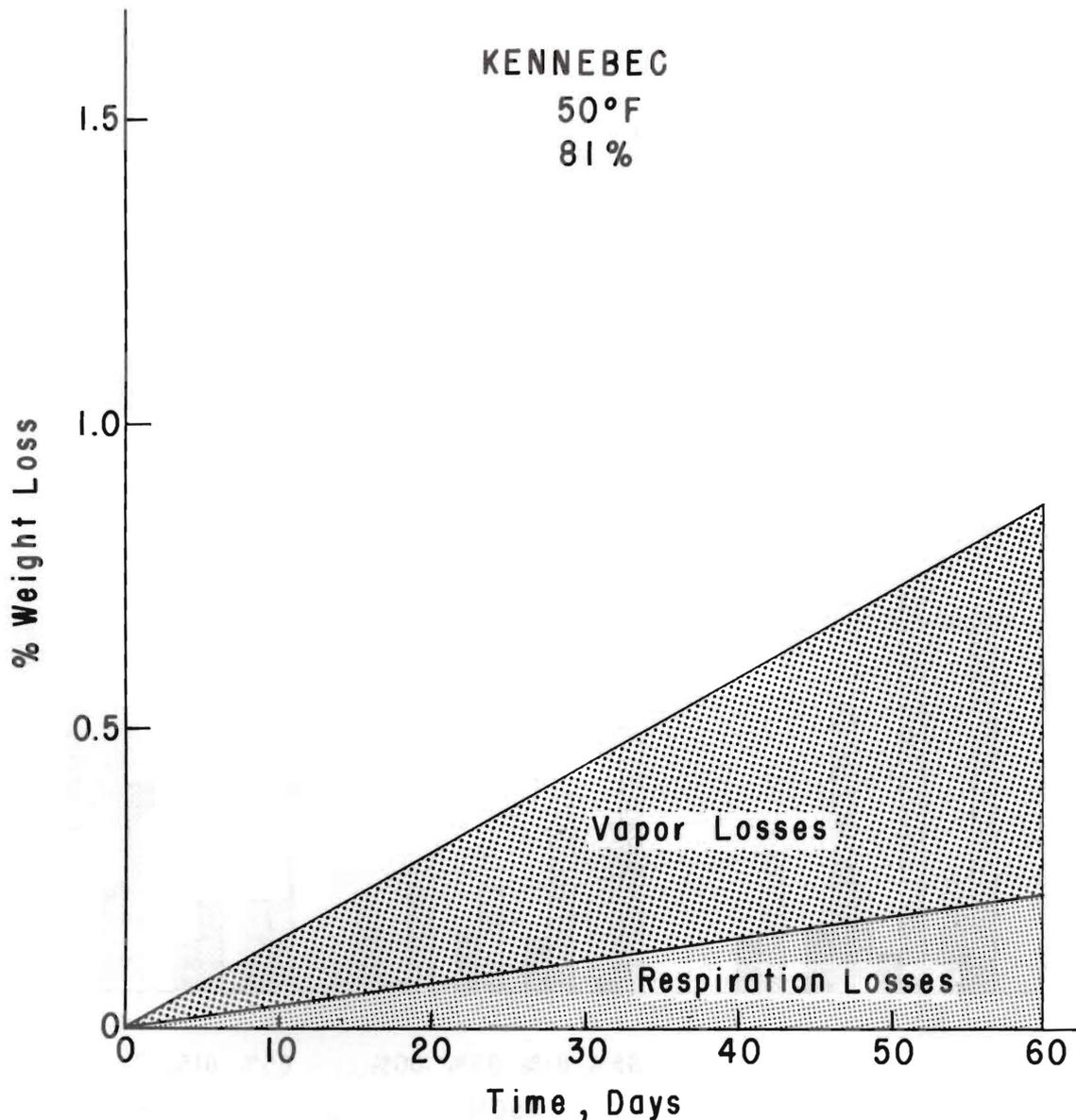


Figure 3. Per cent weight loss partitioned into respiration losses and vapor losses versus storage time in days for Kennebec tubers at 50°F, 81% relative humidity.

The per cent weight loss, based upon the stepwise linear multiple regression analysis, is as follows for the three varieties of potatoes contained in the jars of this test:

**Red Pontiac**

$$\begin{aligned} \% \text{ WL} = & - 4.758010 + 0.0078845434 (\text{day}) - 0.28727911 (\text{RH}) \\ & + 0.0090039037 (\text{day})^2 + 0.15964818 (\text{temp}) - \\ & 2.0910931 (\text{Redsug})^2 \\ & + 128.10492 (\text{CO}_2)^2 + 0.86401284 (\text{SG}) \end{aligned}$$

**Kennebec**

$$\begin{aligned} \% \text{ WL} = & 0.47528404 + 0.017721906 (\text{day}) - \\ & 0.000025782036 (\text{day})^2 \\ & - 0.000056919154 (\text{RH})^2 \end{aligned}$$

**Norgold Russet**

$$\begin{aligned} \% \text{ WL} = & - 29.378479 + 0.012922879 (\text{day}) + 0.0053041428 (\text{RH})^2 \\ & + 2064.7864 (\text{CO}_2) - 0.000022573658 (\text{day})^3 - \\ & 0.0000011941329 (\text{PWT})^2 \\ & - 0.915465 (\text{RH}) + 2.8081818 (\text{temp}) - 0.029276576 (\text{temp})^2 \\ & + 0.0061977319 (\text{PWT}) + 0.46292722 (\text{Redsug}) + \\ & 0.010548053 (\text{RQ}) \end{aligned}$$

The R<sup>2</sup> values were 0.4264, 0.4604, and 0.7150 for Red Pontiac, Kennebec and Norgold Russet, respectively.

**Weight Loss**

To illustrate the nature of the data, the per cent weight loss and the CO<sub>2</sub> production rate are plotted in Figures 1 and 2 respectively for Kenne-

bec tubers stored at 50°F and 81 per cent relative humidity in 1966. The regression line for the per cent weight loss versus days of storage is plotted in Figure 1. The regression line in Figure 2 is for the total respiration losses which includes both the CO<sub>2</sub> and water vapor losses from the tubers. The RQ is also plotted in Figure 2 but no regression line was determined. The respiratory quotient is a measure of the amount of CO<sub>2</sub> produced over the amount of O<sub>2</sub> consumed. The respiration rates were likewise plotted, but the regression lines were not drawn. However, the regression line for respiration rates is parallel to the line drawn for the total respiration losses.

After the respiration rate losses have been integrated, the cumulative respiration losses can be plotted as in Figure 3. Also, the total weight loss of the tubers in the jars is plotted. The difference between the respiration losses and the total weight loss is the loss due to vapor pressure differences between the tubers and the surrounding air. For this particular example, the respiration losses are about one-third of the total weight loss of the tubers.

Table 2 summarizes the total weight loss and weight loss due to respiration after a 60-day storage period for various varieties, years temperatures and

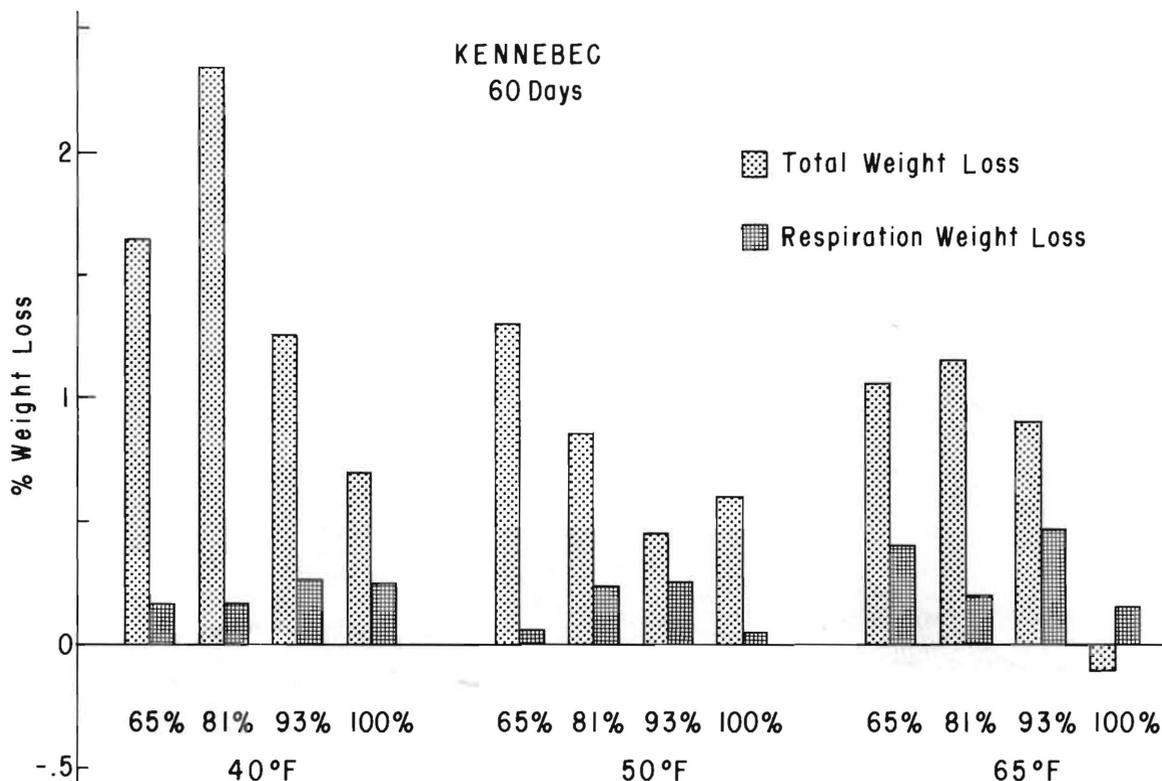


Figure 4. Total weight loss and respiration weight loss at 60 days for Kennebec tubers stored under various temperature-humidity conditions.

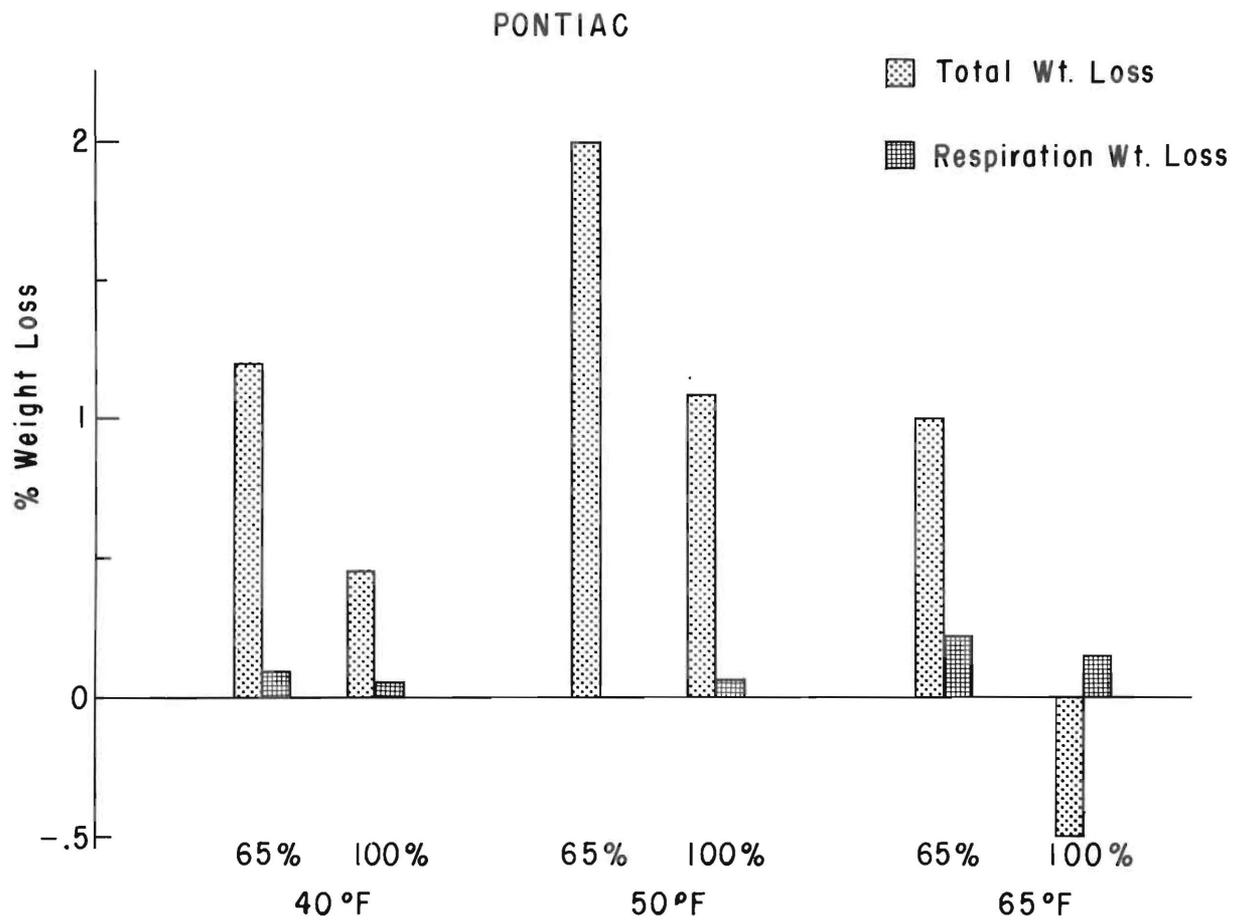


Figure 5. Total weight loss and respiration weight loss at 60 days for Pontiac tubers stored under various temperature-humidity conditions.

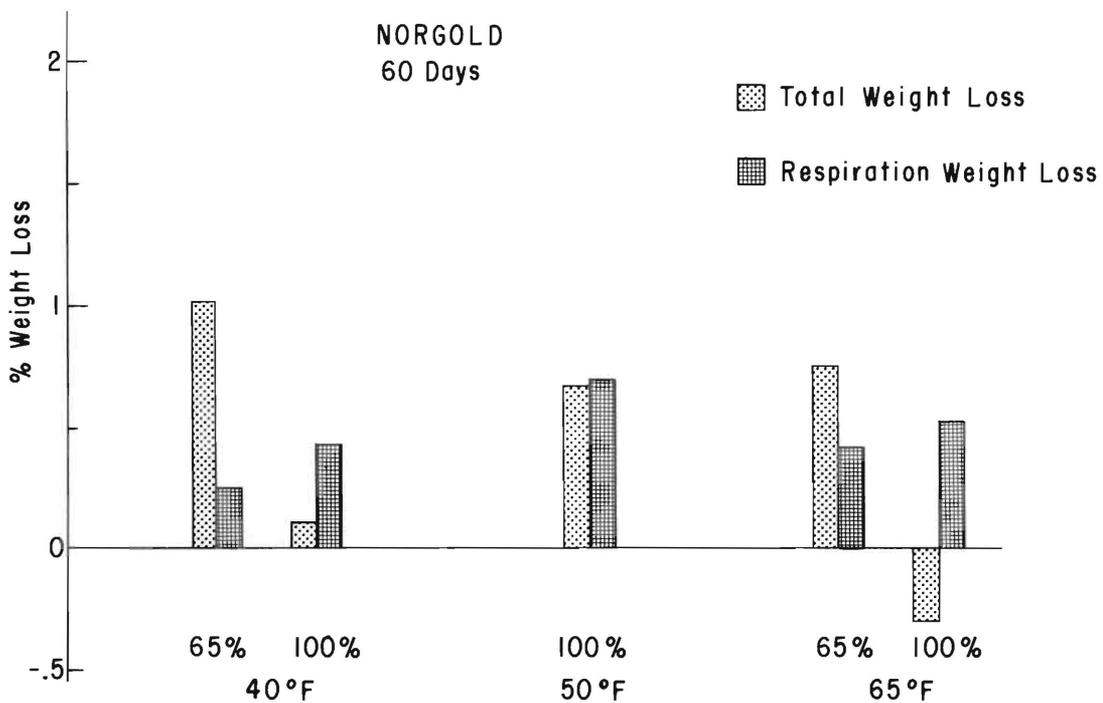


Figure 6. Total weight loss and respiration weight loss at 60 days for Norgold tubers stored under various temperature-relative humidity conditions.

**Table 2. Total Weight Loss and Weight Loss Due to Respiration for Kennebec, Norgold Russet, and Red Pontiac Tubers held at Different Temperatures and Relative Humidities for 60 Days Following Harvest.**

Treatment Variable	Total Weight Loss (%)	Respiration Weight Loss (%)	Per Cent of Total Weight Loss Due To Respiration
<b>Variety<sup>1</sup></b>			
Kennebec	.78a <sup>5</sup>	.20a	28.6
Norgold Russet	.43b	.46b	100.0
Red Pontiac	.65a	.12a	18.5
<b>Temperature<sup>2</sup></b>			
40°F (1967)	1.11a	.21a	18.9
50°F (1966)	1.00a	.19a	19.0
65°F (1968)	.46b	.30a	65.2
<b>Relative Humidity<sup>3</sup></b>			
65%	1.35a	.21a	15.6
81%	1.46a	.20a	13.7
93%	0.87ab	.33a	37.9
100%	0.41b	.15a	36.6
<b>Relative Humidity<sup>4</sup></b>			
65%	1.25a	.20a	16.0
100%	.26b	.21a	80.8

<sup>1</sup>Variety averages based on measurements taken at: 40°F and 65% relative humidity (RH), 40°F and 100% R.H., 50°F and 100% R.H., 65°F and 65% R.H., and 65°F and 100% R.H.

<sup>2</sup>Temperature averages used on measurements taken on: Kennebec at 65, 81, 93, and 100% R.H., on Red Pontiac at 65 and 100% R.H. and Norgold Russet at 100% R.H.

<sup>3</sup>Relative humidity averages based on measurements taken on Kennebec at 40, 50 and 65°F.

<sup>4</sup>Relative humidity averages based on measurements taken on Kennebec and Red Pontiac at 40, 50 and 65°F and Norgold Russet at 40 and 65°F.

<sup>5</sup>Letters refer to comparisons between varieties and relative humidities. Means with the same letter do not differ at the 5% level using Duncan's multiple range test.

relative humidity conditions. The two late varieties, Kennebec and Red Pontiac, had a greater total weight loss than the earlier Norgold Russet. This may have been due to a thicker periderm on the early maturing Norgold Russet tubers, which would be a better barrier against moisture loss.

The data for weight loss at the different temperatures are not directly comparable since 40°F was used in 1967, 50°F in 1966 and 65°F in 1968. It would be expected to have the greatest weight loss at 65°F. However, since this was not the case, the data suggest the tubers studied in 1968 were more mature than those used in 1966 and 1967. Respiration weight loss did tend to be higher at 65°F than at the lower temperatures.

Only a limited amount of data was available on tubers held at 81 and 93 per cent relative humidity, though weight loss at these and at 65 per cent relative humidity was greater than at 100 per cent. With the limited data available, the differences in respiration weight loss were not significant. More data were available for tubers kept at 65°F and 100 per cent relative humidity. In comparing these

two treatments, there was an obvious difference in total weight loss but none in regard to that lost due to respiration.

### Discussion and Conclusions

This investigation has been concerned with two major factors: (1) determining the factors affecting weight loss, and (2) the contribution of respiration to the total weight loss of the tubers during the storage period. Results indicated that respiration accounted for about one-tenth to one-half of the total weight loss, except when tubers were stored in 100 per cent relative humidity. Under this condition, there was an actual net gain, apparently from the tubers absorbing moisture from the surrounding atmosphere.

These results are mainly indicators of what may happen in storage. It should be noted that the tubers were very carefully handled and were therefore not skinned or bruised. Skinning and bruising potato tubers would increase their moisture production and respiration rate in storage. However, the tubers were subjected to the various experimental conditions immediately upon placement in storage, rather than being subjected to any special curing period. In addition, any microbial infection would give a higher respiration rate.

The data do not illustrate the effect of sprouting on the weight loss or respiration rate. Near the time sprouting began to occur the total weight loss accelerated. Also, the respiration rate increased appreciably as sprouting occurred.

Temperature is one of the primary environmental variables affecting the respiration rate of tubers. By reducing the temperature, the respiration rate is reduced and consequently less energy from the potato tubers is used and less moisture produced from the metabolic reactions. However, in this study lower temperatures did not result in less total weight loss if the relative humidity was not changed.

A high relative humidity reduces the vapor pressure difference between the potato surface and the unsaturated air, thus reducing vapor losses. Previous studies have indicated that moisture loss is not affected appreciably by higher air flow rates so long as the air has a high moisture content.

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