POTATO STORAGE

During the Curing Period

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Proper manipulation of air flow, temperature and relative humidity can minimize weight loss, promote wound healing and prevent breakdown of sound potato tubers. Common storage practice in the Red River Valley has been to store freshly harvested potatoes initially for one to two weeks at 55° to 60°F. (13° to 16°C), at high relative humidity and with no air flow to provide environmental conditions necessary for wound healing.

There is general agreement on the need for a high relative humidity during this initial storage period, and for rapid cooling to about 50°F. (10°C) with high velocity air circulation if potatoes are diseased or have been frosted. However, temperature and air flow recommendations for the initial storage of sound tubers varies considerably.

Sparks (13), in Idaho, suggests that temperatures between 45° and 50°F. (7° to 10°C) and a relative humidity of 85 per cent with intermittent air flow will help heal the wounds. Wilson (16), in Washington, suggests a temperature of 50°F. (10°C) and 90 per cent relative humidity for 10 to 14 days during the curing period and then cooling the tubers to the holding temperature. He suggests using air flow to remove field heat rapidly during the curing period and then circulating a lower constant air flow to prevent hot spots. McCurdy (7), in Pennsylvania, suggests a 60°F. (18°C) temperature for a seven- to 10-day period with no air flow during the wound healing period. Schoenemann, et al. (10), in Wisconsin, suggest a 55° to 65°F. (13° to 18°C) temperature, 85 per cent relative humidity for 10 to 14 days with 0.8 cfm/cwt. air flow rate during the curing period.

Watson and Staley (15) developed equations for the temperature distribution and determined half-cooling times at different depths in a model potato bin over a temperature range from 40° to 80°F. (4° to 27°C) and air velocities from 1.3 to 17.7 cfm/sq. ft. Bakker-Arkema, et. al. 1, 2) developed the theory and a computer simulation of simultaneous heat and mass transfer to cool deep beds of biological products under varying inlet air conditions. They verified their mathematical simulations by investigations with wet cherry pits, sugar beets and pea beans. Other studies on the heat and mass transfer in deep beds have been conducted by Listov (6), Wang, et al. (14), Young (17) and Ngoddy, et al. (8). Soule, et al. (12) experimentally determined some heat transfer characteristics of Florida citrus fruit for pre-cooling.

Butchbaker, et al. (5) previously discussed the factors affecting the weight loss of individual po-

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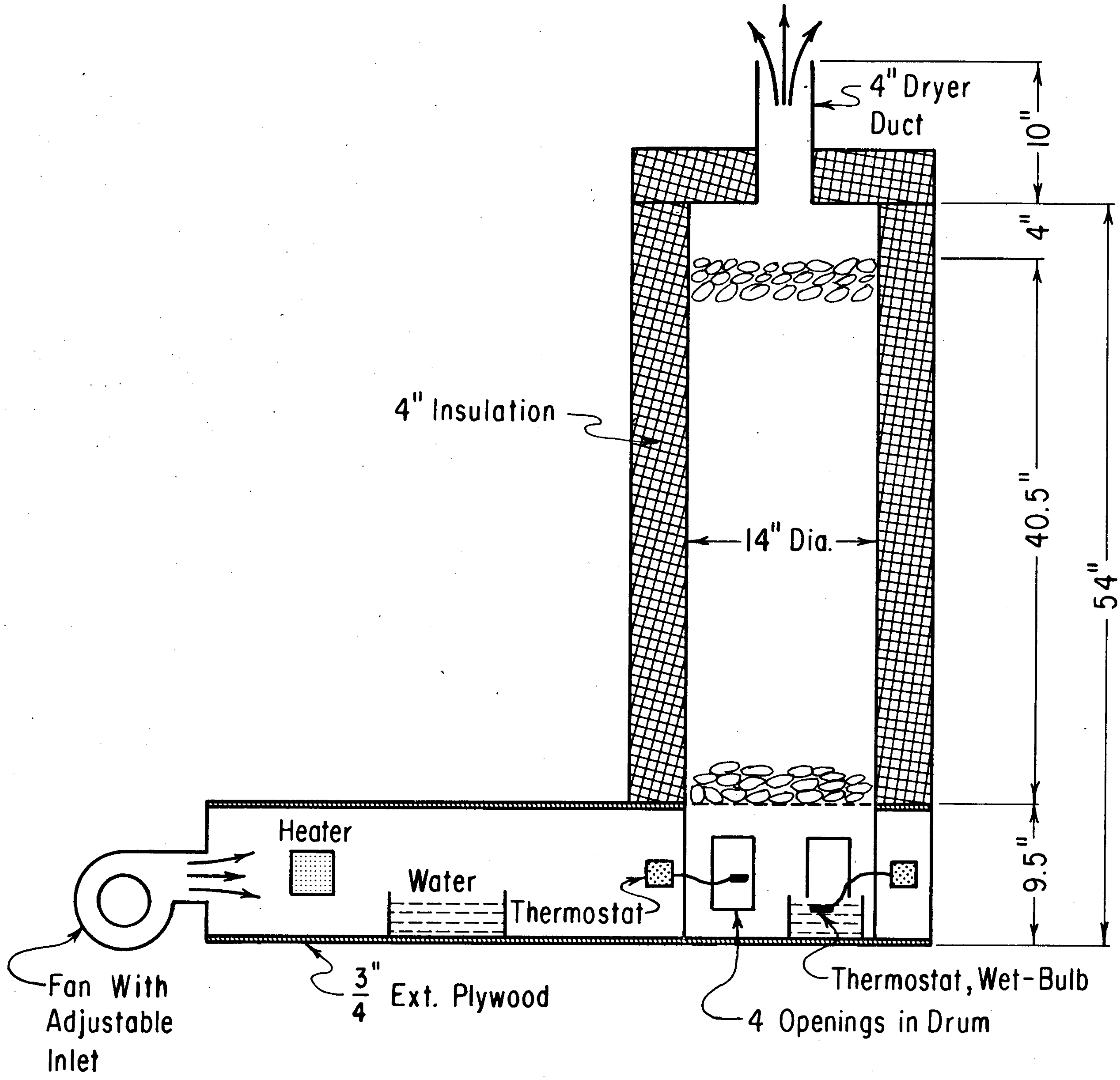

Fig. 1. Sketch of model potato storage bins.

tato tubers. Other researchers who have conducted experiments on weight loss of potatoes are Burton (3), Ophius (9) and Schippers (11, 12). Essentially, weight loss is affected by storage conditions (air temperature, relative humidity, air velocity), and by such biological variables as tuber weight, variety and infection from decay-producing organisms. Weight loss is partly a reflection of the resistance to moisture flow through the wounded areas of the tuber. As the wounded areas heal, they have a lower permeability to moisture transfer from the interior of the tuber to the air flowing past the tuber. No experimental studies have been conducted on the heat and mass transfer from the potatoes to the surrounding air during the curing period.

In this investigation, quantitative data were obtained during the curing period on the weight loss; temperature of the tubers during heating, cooling and ventilation; and the effect of initial storage conditions on moisture transfer from the tuber to the air.

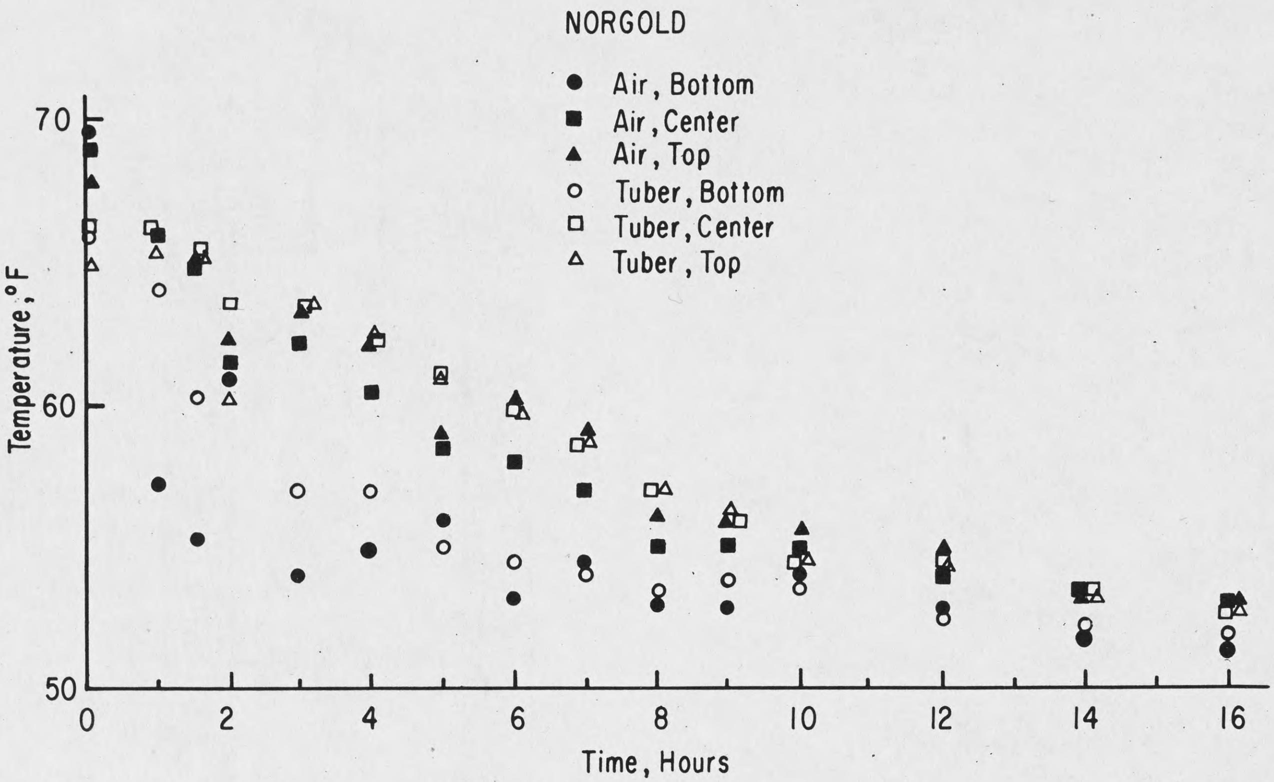

Fig. 2. Cooling of Norgold tubers from a relatively high temperature under natural convection and conduction conditions.

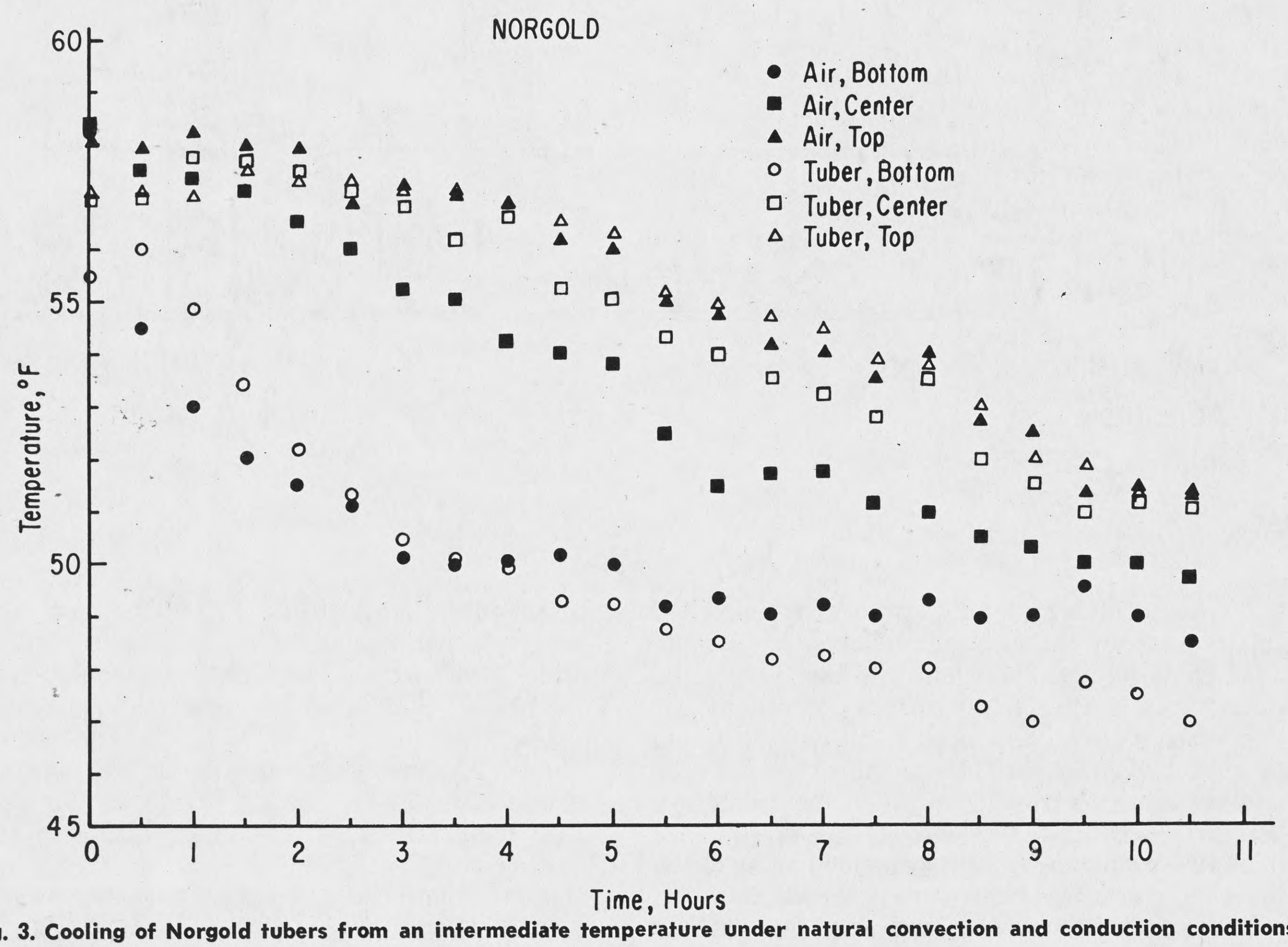

Fig. 3. Cooling of Norgold tubers from an intermediate temperature under natural convection and conduction conditions.

MATERIALS AND METHODS

Phase 1 of this investigation consisted of determining cooling rates and temperature distributions of potato tubers in model bins, while phase 2 consisted of determining the weight loss of the tubers and the temperatures of the tubers and air during the curing period.

A model bin was constructed from steel drums as illustrated in Figure 1. The drums were altered to have a perforated floor constructed of hardware cloth, were insulated and had a cover with a four-inch diameter outlet duct. The cylinders were wrapped with four-inch fiber glass insulation. Air was supplied through a plenum chamber located at the bottom. Electric heaters in the plenum were controlled by a thermostat. A pan of water with a heating element provided for moisture supply and was controlled by a thermostat with a wet-bulb sensing element. Air flow was supplied by squirrel cage fans. Inlet areas to the fans were regulated to control the air flow rate.

Temperatures in the model bins were measured by 24-gauge copper-constantan thermocouples with temperatures recorded continuously on a recording potentiometer. Tuber temperatures were measured by thermocouples inserted into the center of the tubers. Relative humidity was measured periodically with a Honeywell lithium chloride sensing element. Air velocity was measured by averaging hot-wire anemometer readings taken at the exit of the experimental model bins.

Cooling Studies: Norgold Russet and Red Pontiac potatoes were obtained from local growers for the cooling studies. Some studies were conducted with air flow and others with no air flow but permitting thermal equilibrium to be established in the bins.

Curing Studies: Red Pontiac potatoes grown at the Red River Valley Potato Research Farm near Grand Forks, North Dakota, were lifted using a small mechanical digger and then carefully hand picked and placed into sacks. Tubers were washed after transporting to Fargo, placed into three model bins and subjected to various experimental conditions (Table 1).

After a month of storage, the tubers were taken out of the bins and weighed to determine their weight loss. The effect of the three storage conditions on the permeability of the skin to moisture transfer following storage was determined using the method developed by Butchbaker (4).

RESULTS

Cooling Studies: In September and early October, cooling studies were conducted on Norgold Russet and Red Pontiac tubers. Results of these studies are illustrated in Figs. 2 through 4 for Norgold Russet and in Figs. 5 and 6 for Red Pontiac. Air and tuber temperatures at three locations in the model bin (bottom, center and top) were measured.

In Figs. 2 and 3, cooling Norgold Russet tubers from a relatively high storage temperature and from an intermediate storage temperature are illustrated respectively. Air temperatures near the bottom achieve near equilibrium conditions within four to five hours after the initial conditions are changed. Temperatures of tubers near the bottom closely follow the air temperature at that level but do show some lag. Air temperatures and tuber temperatures at the center and at the top lag considerably behind the bottom air and tuber temperatures. Center and top air and tuber temperatures at equilibrium are approximately equal.

The effect of turning on the fan and heater on the Norgold Russet tubers that have been held at a constant temperature for a few days under no-air-flow conditions is illustrated in Figure 4. Within

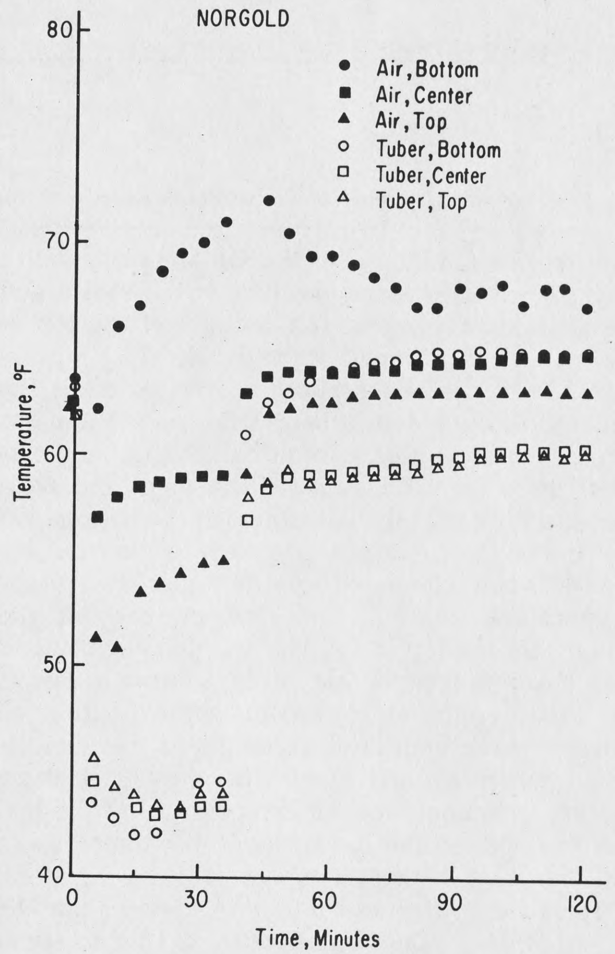

Fig. 4. Effect of turning on a fan and heater on air and tuber temperatures for Norgold tubers stored previously under no air flow conditions.

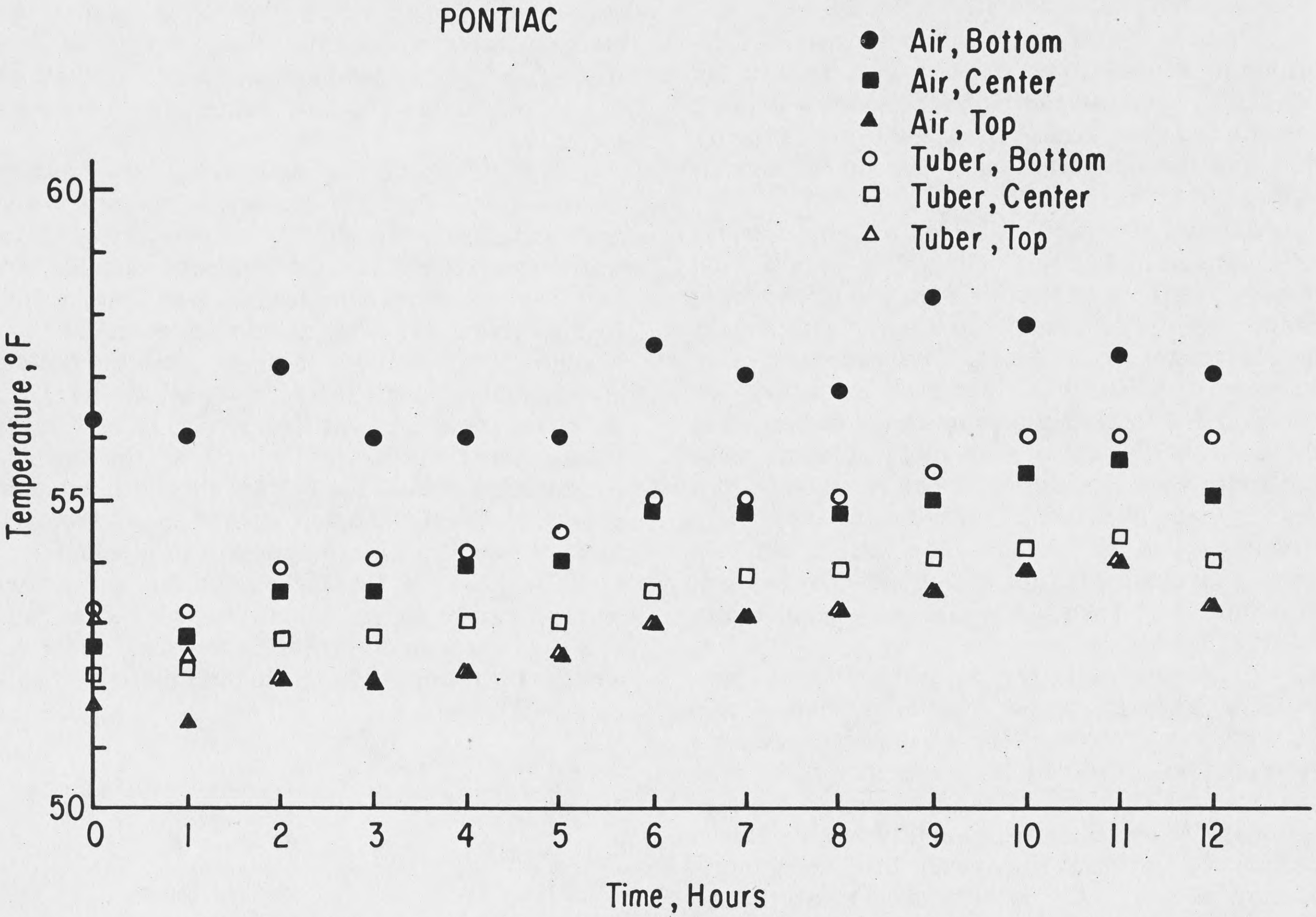

Fig. 5. Tuber and air temperatures of Pontiac tubers stored under natural convection (no forced air flow) conditions.

the first few minutes after the fan and heater have been turned on, the temperature of the tubers and the air temperatures at the center and the top of the model bin dropped appreciably. This is probably due to the evaporation of free water in the bin and on the potato tuber surfaces. As the moisture evaporates, heat is required and initially this heat comes from the tubers themselves and from the air within the bin. The tubers at the bottom had the lowest temperature and led in thermal response when compared to the other two tuber temperature locations. Air temperatures at the center and the top of the bin dropped slightly and then began to recover and never did drop as low as the tuber temperatures. After approximately 45 minutes, near equilibrium conditions were established for tuber and air temperatures. At these equilibrium conditions, air temperature at the bottom was highest and the bottom tuber temperature had the next highest temperature. Air temperatures at the center and top were higher than the corresponding tuber temperatures. This is for a condition where fans were turned on to regulate the incoming air temperature at approximately 67.5°F. (19.7°C) and when the initial temperatures were approximately 5°F. (2.8°C) lower.

Temperatures of Pontiac tubers placed under no-forced-air-flow conditions in the model bins are shown in Figure 5 Some natural air circulation occurred through the bins because the entrance and the exits were not sealed completely. This permitted some moisture to escape and the tubers thus tended to have less condensation. Bottom air temperature is representative of the room walk-in cooler temperature. These freshly-harvested potato tubers at about 52°F. (11°C) were placed directly into the bins at an outside control temperature of about 57°F. (14°C). This illustrates the time it takes for the tubers to rise in temperature under no-forced-air-flow conditions. The rate of rise in temperatures is much greater for the bottom tubers than for the center and top tubers. This is probably because the evaporation of moisture within the bin keeps the center and top tubers cooler and also because of the thermal lag.

The effect of turning a fan and heater on Red Pontiac tubers previously stored under constant temperature no-air-flow conditions for a few days

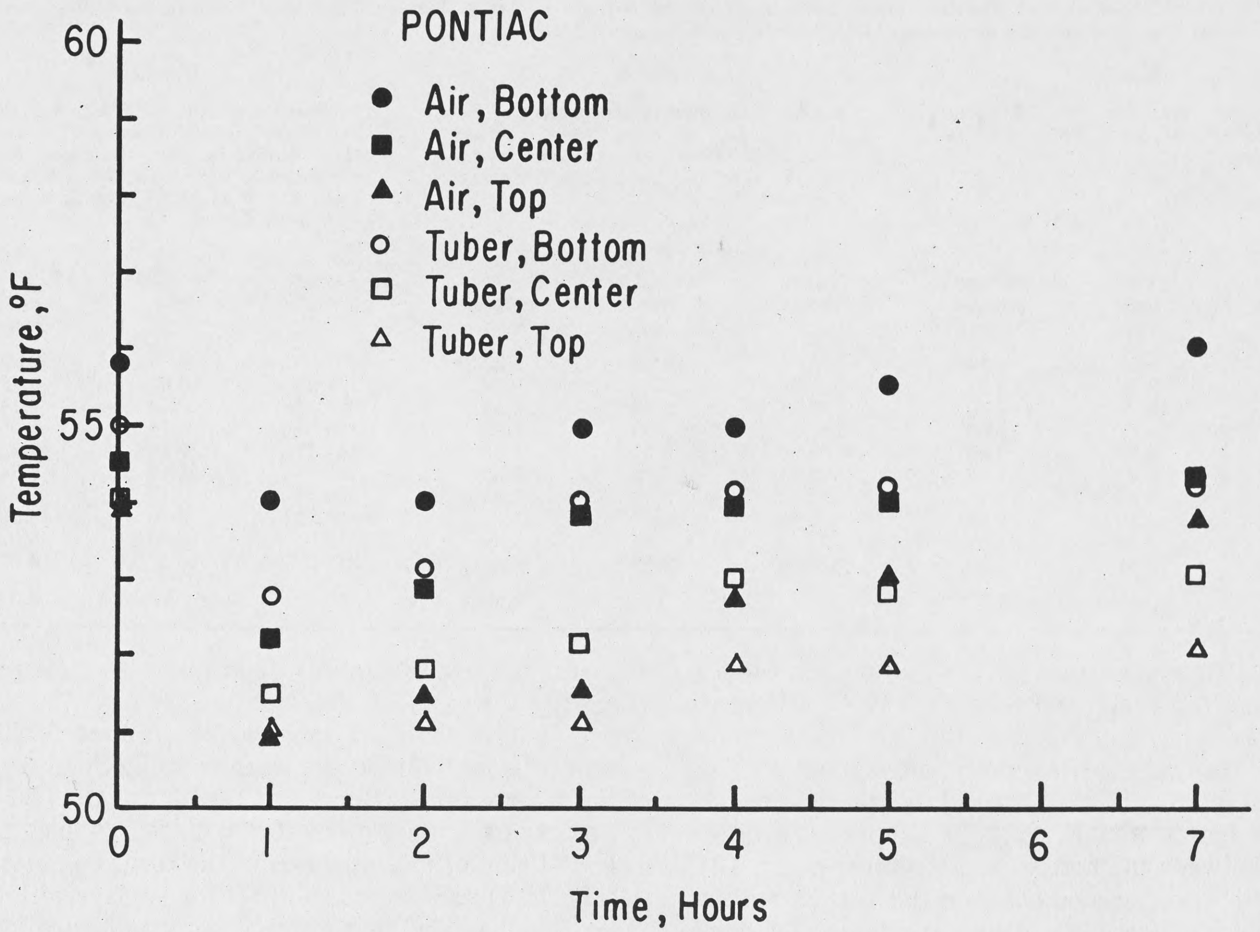

Fig. 6. Effect of turning on a fan and heater on air and tuber temperatures for Pontiac tubers previously stored under no air flow conditions.

is illustrated in Figure 6. Figure 6 has a longer time base than that used in Figure 4. Note again the drop in tuber temperatures followed by a slow rise until a condition near equilibrium in the bin was established. Thermal equilibrium occurred much sooner when a fan was turned on forcing air through the bin compared to only natural air circulation. With air flow there is a 2°F. (1.1°C) difference in air temperatures between the bottom and top and a 3°F. (1.7°C) difference between the tuber temperatures between the bottom and top. The tuber temperatures are 1° to 2°F. (.6° to 1.1°C) lower than the corresponding air temperature with air flow.

Curing: Red Pontiac tubers were placed in the model bins on October 16 and removed on November 21, 1969. Weight loss of the tubers placed under the three conditions are presented in Table 1. Bin A had a continuous air flow rate of 0.5 cfm/cwt with air at 45°F. (7.2°C) and 85 per cent relative humidity. Bin B had no air flow during the curing period at 50°F. (10°C) for 14 days, and then for the remainder of the study had an air flow rate of 0.8 cfm/cwt at 45°F. (7.2°C) and 85 per cent relative humidity. Bin C had a 50°F. (10°C) temperature with 85 per cent relative humidity and intermittent air flow during the first 10 days. Following this, Bin C had an air flow rate of 0.8 cfm/cwt at 45°F. (7.2°C) and 85 per cent relative humidity.

Individual weights and weight losses of 10 tubers from each bin are presented in Table 1. The environmental condition providing the least weight loss (1.92 per cent) was Bin A with a continuous air flow rate of 0.5 cfm/cwt and 45°F. (7.2°C). Weight loss for the conventional storage practice with a 14-day curing period at 50°F. (10°C) (Bin B) was 2.03 per cent, or just slightly higher than Bin A. Tubers stored in Bin C had the highest weight loss (4.52 per cent) of the three storage conditions being over twice that of the other two treatments.

Average temperatures during the storage period are presented in Table 2 for the air temperatures and the tuber temperatures at the bottom, center and top of the model bins for the three storage methods. A more sensitive measurement of temperature differences between the bottom and top for tubers in air were made by using a thermopile. These results indicated that Bin A had a 4.88°

Table 1. Weight loss of Red Pontiac tubers held under different air velocity, temperature, and relative humidity conditions during the first month of storage, October 16 to November 21, 1969.

Bin A			Bin B			Bin C		
Continuous air flow at 0.5 cfm/cwt., 45° F., (7.2 C.) 85% relative humidity.			No air flow during curing at 50° F. (10° C.) for 14 days, then continuous air flow at 0.8 cfm/cwt., 45° F. (7.2° C) and 85% relative humidity.			Intermittent air flow during curing at 50° F (10° C) and 85% relative humidity for 10 days, then continuous air flow at 0.8 cfm/cwt., 45° F (7.2° C) and 85% relative humidity.		
Tuber Weight (g)	Weight loss (g)	Per cent weight loss	Tuber Weight (g)	Weight loss (g)	Per cent weight loss	Tuber Weight (g)	Weight loss (g)	Per cent weight loss
179.59	4.24	2.37	192.22	4.46	2.32	151.00	4.26	2.82
215.72	3.42	1.61	275.04	2.31	0.84	183.68	10.65	5.79
441.60	10.08	2.28	139.98	2.72	1.94	226.77	9.30	4.14
223.64	3.47	1.56	247.78	2.06	0.83	109.81	8.74	7.95
475.67	9.87	2.07	133.83	3.91	2.92	444.77	20.14	4.53
189.39	3.71	1.96	197.71	7.22	3.65	242.45	11.48	4.74
578.28	9.94	1.72	112.73	2.92	2.58	250.35	9.43	3.77
134.90	3.30	2.44	498.69	5.59	1.12	226.72	9.60	4.23
284.03	5.46	1.92	238.83	6.67	2.88	319.04	12.86	4.03
197.19	2.45	1.24	325.08	12.13	3.88	216.97	10.47	4.82
	Average	1.92%		Average	2.03%		Average	4.52%

F. (2.71°C) temperature difference between the bottom and top tuber and 5.74°F. (3.19°C) difference between the bottom and top air temperature. Bin A had an experimentally determined air flow rate of 0.507 cfm/cwt. During the air flow period, Bin B had a 3.81°F. (2.12°C) temperature difference between the bottom and top tuber and a 3.61° F. (2.01°C) difference between the bottom and top air temperatures. It had an experimentally determined air flow rate of 0.855 cfm/cwt. Bin C had a temperature difference of 6.21°F. (3.45°C) between the bottom and top tuber and 5.23°F. (2.91°C) difference between the bottom and top air temperatures. The experimentally determined air flow rate for Bin C was 0.801 cfm/cwt.

Table 2. Average temperatures for air and potato tubers stored in model bins between October 16 and November 21, 1969.

	AIR TEMPERATURE (F)			TUBER TEMPERATURE (F)		
	Bottom	Center	Top	Bottom	Center	Top
BIN A	49.4	48.1	45.7	51.6	45.7	44.3
BIN B No air flow period	46.3	43.5	47.0	45.1	43.3	45.3
Air flow period	50.1	46.8	45.2	49.2	46.5	44.4
BIN C	56.1	54.3	50.6	54.9	51.0	49.1

Average relative humidities at entrance to bins

BIN A 76.0% at 48.8° F

BIN B 82.0% at 47.7° F during air flow

BIN C 61.0% at 56.1° F

Rate of moisture loss was determined for the tubers stored under the various conditions after the tubers were taken out of the bins at the end of the experiment. Tubers stored in Bin A had the lowest rate of moisture loss of the three conditions (Fig. 7). Tubers stored in Bin B for 14 days with no air flow had the next lowest rate of moisture loss, while tubers stored under continuous air flow of 0.8 cfm/cwt at 50°F. (10°C) had the highest rate of moisture loss. These results would tend to indicate that the tubers stored under low air temperature and high humidity and low air flow rates suberized adequately and thus had a low permeability or moisture transfer at the end of the study. The tubers stored under conventional methods and under the higher temperature and higher air flow rates had a high permeability for moisture transfer at the end of the experiment.

DISCUSSION

This investigation presents experimental results of the cooling rates of Norgold Russet and Red Pontiac tubers and the weight loss of the tubers stored under different curing conditions.

In the cooling rate studies, tuber temperatures dropped significantly just after the fans were turned on. This drop of 15° to 20°F. (8° to 11°C) in tuber temperatures probably was due to the heat needed to evaporate the free moisture on the tuber surfaces. Some of the experimental results from cooling tubers in the model bins may not be applicable to large storage bins. However, the qualitative results may be similar. Large bins would have more

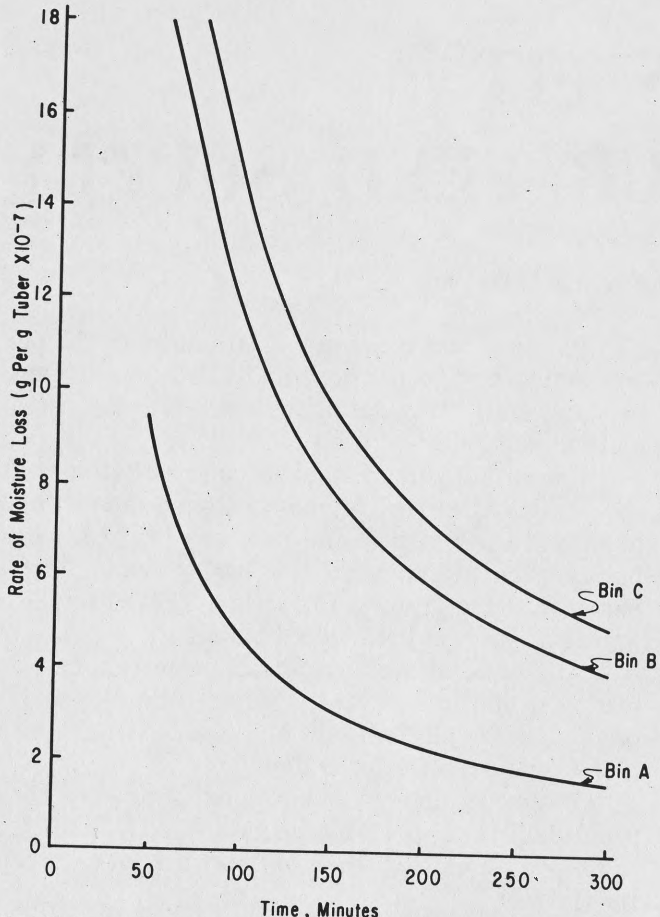

Fig. 7. Rate of moisture loss of Pontiac tubers at end of storage trials (Bin A - continuous 0.5 cfm/cwt air flow at 45° F and 85% r.h. Bin B - no air flow at 50° F for 14 days, then 0.8 cfm/cwt air flow at 45° F and 86% r.h. Bin C - 50° F, 85% r.h. and intermittent air flow during curing, then 45° F, 85% r.h. and 0.8 cfm/cwt during holding).

inertia for change. Thus, a large bin may not have as great a temperature difference as a model bin when conditions are suddenly changed at air inlets.

Analytical studies of the heat and moisture transfer of the tubers during the curing period and the initial cooling are needed. The above experimental results may be an indicator of what would happen. However, mathematical simulation of the processes may indicate more precisely the nature of the temperature changes due to varying inlet air conditions. Many storage problems arise during the curing and cooling periods, creating a complex situation which would make a mathematical simulation difficult. Therefore, any mathematical simulation study should be followed by an experimental verification study.

The curing studies indicated that storage at 45°F. (7.2°C) temperature with continuous air flow of 0.5 cfm/cwt and relative humidity of 85 per cent was a slightly better storage condition during curing than the conventional method of 14 days of no air flow followed by a high air flow rate of 0.8 cfm/cwt and a low temperature of 45°F. (7.2°C). This should be verified in a larger storage bin for these species of potatoes. Sparks (13) has indicated that this method is equally as good as the conventionally used curing methods.

Temperature differences with air flow indicated that tubers had a 1° to 2°F. (.6° to 1.1°C) lower temperature than the corresponding air temperature at that particular height in the model bin. There was a 3° to 5°F. (1.7° to 2.8°C) temperature difference between the bottom and top tuber and air temperatures in the model bins, with air flow. This may be a slightly greater difference than in large bin storages. This should be verified by experimental testing in large storage bins.

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