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The Relation of Respiration, Transpiration, and Loss of Weight to Surface Area and Number of Lenticles in Potato Tubers

Walter H. Michaels
South Dakota State University

THE RELATION OF RESPIRATION, TRANSPIRATION AND LOSS OF WEIGHT TO SURFACE AREA AND NUMBER OF LENTICLES IN POTATO TUBERS.

By

WALTER H. MICHAELS

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INTRODUCTION

Although considerable work has been done on the respiration of potato tubers most of it has been concerned with internal changes. Some very interesting correlations have been secured but the more recent work, particularly that of Bennet and Bartholomew (8) points to the permeability of the epidermis as the big controling factor in respiration.

It is a commonly accepted fact that the purpose of lenticles is to serve as an aperture through which the gases concerned in respiration may pass. The lenticles of the potato tuber should be no exception. The surface area should also greatly influence respiration since a relatively larger surface is exposed in small potatoes, with a consequently easier access of oxygen to the tissues. Indeed Hoffman (20) has found the surface area to be a limiting factor.

The following study was undertaken, with these facts in mind, to determine if a definite correlation exists between the number of lenticles, surface area and the rate of respiration in potato tubers.

REVIEW OF LITERATURE

In reviewing the available literature on potato respiration it was found to be widely scattered. To obtain as clear an understanding of the work done by previous investigators as possible, this material was classified under various heads under which it seemed naturally to fall. As all of this literature is more or less pertinent to the subject at hand the writer has taken the liberty to present it here without any further condensation.

Food

Muller-Thurgau (25) was the first to note a correlation between sugar content and respiratory activity. His results were confirmed by Butler (10); Muller Thurgau and Schneider-Orelli (26) also found this to be true, but in addition they found that respiratory intensity increased with the age of the tuber, which they attribute to a greater sugar content in old potatoes. Appleman (4) found that both glucose and sucrose accumulate at low temperatures, that the increase in sucrose is more rapid at first than that of glucose, but by the end of six weeks storage at low temperatures the percentage of glucose is about twice that of sucrose. Spoehr (34) in his very excellent work on the carbohydrates of the cacti, finds that the rate of respiration is not controlled by any one group of sugars, such as hexoses, which may be present in cactaceae in varying amounts, but do not influence the rate of respiration. He also found that in cacti a low water content accompanied by a high temperature bring about a decrease of monosaccharides, while a high water content and low temperature are associated with an increase of monosacchorides and pentosanes. In speaking of anerobic respiration, he states that the plants consumed as much or slightly more carbohydrates than those kept in air. From this he draws the conclusion that the carbon dioxide emission of plants under anerobic conditions is the result of carbohydrate respiration.

Hoffman and Sokolowskii (21) found that respiration of potatoes with high water and protein content might be lower than in those low in water and protein. They draw the conclusion that water and nitrogen content of potatoes are not invariable in their influence on respiration, as they are in grains. Appleman (2) found that there is no change in the relative magnitudes of the following forms of nitrogen during the rest period of the potato tuber: proteose and peptone; diamino acids and other bases; monoamino acids and amides; protein lipoid, organic extractive and inorganic phosphorous, each remaining constant up to the time of sprouting. The magnitudes of these substances are not the same in the seed and stem ends.

In this connection it is interesting to note that Griecke (16) found that in the case of no-rest period tubers, not only was not all the food material used to mature a plant, but it was possible to recover the seed potato, replant it and secure a second crop. These tubers lost very little in weight. This would indicate that under all normal conditions there is an enormous excess of food available. Spoehr (33) in speaking of suitable material for studies in respiration says: "There must also be a sufficient supply of carbohydrate food material, for it was found that as soon as the carbohydrates were exhausted, the nature of carbon dioxide evolution changed greatly."

Enzyme Action

Appleman (2 & 5) in his studies on the potato tuber found active diastase and invertase present at all stages of the rest period. It was found that these did not increase until the tubers began to sprout. In his study of oxidase and catalase activity he came to the conclusion that there was no correlation between the rate of oxidase activity and the rate of respiration in potato tubers but that there is a definite correlation between catalase activity and respiration intensity.

Pack (27) in a study of Juniper seeds found catalase activity and respiration definitely correlated and influenced by the same conditions except when seeds were submerged. In submerged seeds catalase activity gradually increased while respiration did not, showing that catalase activity may increase without influencing respiration. Crocker and Harrington (13) also established a close correlation between catalase activity and respiratory intensity. Atwood (7) found catalase activity and respiratory activity to run parallel in wheat which had been treated with formaldehyde.

Appleman (4) found a guaiaconic acid peroxidase very active in potato tubers at the beginning of the rest period, with a gradual increase as the end of the rest period approaches. Low temperatures had no apparent effect on it.

Other enzymes said to be present in the potato are zymase, which is particularly associated with yeast and is responsible for the alcoholic fermentation of sugar; and carboxylase which has the property of removing the carbon dioxide from carboxyl groups. Altogether the relation of enzymes to respiration is as yet very little understood, Palladin's theory probably being the best explanation yet advanced.

Appleman (3) found the Van't Hoff velocity coefficient for potato catalase to be 1.5 for 0 to 10°. At 20° destruction of potato catalase began and is complete at 50°. Diastase activity in potatoes in cold storage increased which Appleman believes is due to the activation of zymase by free acids, which are liberated by the greater permeability of protoplasmic membranes at low temperatures.

Acidity

Appleman (3) reports the expressed potato sap as strongly acid. He finds that low temperature does not change the total acidity, but probably effects the permeability of the protoplasmic membranes, and thereby allows the acids to reach zymogens more rapidly than under normal conditions. He considers the reduction of catalase activity to be due to free acids.

Richards (29) in his studies on acidity and gas interchange of cacti finds an increase in respiratory activity with an increase in acidity. Spoehr (34) working with the same type of material finds that acid formation is benefited by the presence of oxygen although there is a decided acidification even in the absence of oxygen. He finds further that in anerobic respiration the carbon dioxide produced does not arise from the breaking down of organic acids to the same extent as in normal air. Spoehr found alcohol formation in potatoes to be exceedingly small.

Temperature

Probably some of the earliest observations on the effect of temperature on the potato tuber were those made by Muller-Thurgau (l. c.). He found that tubers at temperatures between -2 and 3°C accumulated sugar in large amounts, as much as 3.5% being found in some potatoes which had been held at 0° for 30 days. It was also found that this sugar formation gradually decreased with a rise in temperature until at 10° none at all was formed. This is of importance because it was found that when these "sweet" potatoes were brought to a temperature of about 20°, their respiration rate rapidly rose, reaching its maximum on about the second day and from then on gradually declined until it approximated that of normal tubers. The entire process taking from 6 to 10 days which corresponds to the time required for the potatoes to again become normal in sugar content. Appleman (1) found that four-fifths of the sugar accumulated at low temperatures was reconverted into starch and the other one-fifth is lost when the "sweet" tubers were held at room temperature. This loss of sugar apparently is due to respiration. Muller-Thurgau (l. c.) also found, that in tubers held at 20° for some time and then gradually increased showing that the presence of sugar, influenced the rate of respiration even at this low temperature. As previously stated, he found that at 10° the rate at which sugar accumulated and the rate of respiration balanced each other. A difference in different varieties and even different potatoes of the same variety were observed both in the amount of sugar accumulated and in the rate of respiration. Hoffman and Sokolowiskii (l. c.) found similar differences in the rate of respiration.

In this connection Appleman (1) says: "From 46° to 50°F the processes of respiration and synthesis of starch from sugar consume all the sugar that is formed by the action of diastase, therefore no sugar accumulates. Below this temperature the two former processes are inhibited to a much greater extent than the latter. Consequently starch begins to accumulate. At 32°F respiration and starch synthesis are so slight that a large percentage of the sugar formed accumulates, the supply is greater than the consumption."

Muller-Thurgau and Schneider-Orelli (l. c.) found that exposure to high temperature for some time acted as a permanent stimulus to respiration. Potato tubers exposed to a temperature of 40° for several hours and then transferred to room temperature show a gradual increase in respiratory intensity which reaches its maximum after a lapse of twenty-four hours. Exposure to higher temperatures for example 44° results in a permanent increase in the respiratory intensity which indicates a permanent change in the organism. No effects were observed at temperatures below 38°. In this instance the difference between the maximum intensity of respiration in the heated tubers and that of the unheated tubers is proportional to the difference between the minimal temperature and the increased temperature to which the tubers were exposed. They consider that high temperature effects the protoplasm adversely as does old age; as a result the leucoplasts and the enzymes are less active, so less starch is formed. For instance at 18° previously heated potatoes contain a relatively large amount of sugar; at 0°, at which temperature sugar accumulation is greatest in normal tubers, there was only very slow sugar formation, indicating that the high temperature had an injurious effect on sugar formation although the amount of diastase is apparently unaltered. When previously heated tubers were wounded there was no immediate respiratory response and even when recovery from the heating effect had apparently been made the maximum intensity of respiration due to traumatic stimulus never reached as high a degree as in the unheated wounded tubers.

These results would tend to show that Van't Hoff's law does not hold for respiratory activity at higher temperatures. This is of course to be expected from the very nature of the respiratory process which Appleman (5) defines as: "the product of living cells and is capable of bringing about at low temperature, the oxidation of organic substances which in the laboratory are oxidized only by employing very high temperatures. However, Bennet and Bartholomew

(l. c.) find Van't Hoff's rule to hold for the temperatures between 45° and 50°. A lowering of 10° roughly halving the rate of respiration.

Bennet and Bartholomew (l. c.) also found what they consider a minimum rate of respiration. According to their work, the respiration rate at 0° and 2½°C was markedly higher than at 5° and again rose at temperatures above 5° when potato tubers were stored for some time at these temperatures. Hopkins (22) has recently obtained results which indicate that the minimum rate of respiration occurs at a slightly lower temperature. Working with the temperatures ranging from 0.83° to 11.5°, he finds that the rate of respiration at 0° is higher than at 4.5° but the curve for the entire range of temperatures shows the minimum to be at about 3°C. The difference between these two sets of results is probably due to the use of different varieties of tubers.

Ziegenbein (38) found the maximum rate of respiration to be about 112°F above which point it again gradually decreased.

Muller-Thurgau and Schneider-Orelli (l. c.) found increased respiration in potato tubers after the warm bath treatment. Iraklonow (23) also found a rest in respiration of potato tubers after treatment in the warm bath, however, at the end of a few days the respiratory rate fell to normal and did not again rise until the beginning of germination.

Moisture

Palladin and Sheloumova (28) found that when potato tubers were exposed to drying in the air at room temperature, the intensity of respiration gradually increased the first day, in spite of a heavy water loss, but the further loss of water caused a distinct lowering of this energy. When the same tubers were immersed in water the respiration was again stimulated for a few days, after which it fell to the normal ratio. Another part of the material was kept in a moist chamber instead of the laboratory room, but it was found that the production of CO_2 in this latter test differed little from that in the remaining tubers. This is claimed to show that a slight loss of water is sufficient to weaken the energy of respiration. No definite correlation between the amount of water lost and the intensity of respiration was established.

Appleman's (1) also notes that moisture influences respiration favorably but does not give any results to prove this.

Hoffman and Sokolowskii (l. c.) in their work, show the effect of water and nitrogen content on respiration. They found that potatoes with high water and protein content may be lower in respiration than those low in water and protein. They conclude that water and nitrogen content are not invariable in their influence on respiration of potatoes as they are in grains.

Butler (12) states that potatoes give off moisture at all times in amounts that, while greater at higher than at low temperature, is always sufficient to saturate the surrounding atmosphere in a short while. He also found that potato tubers lost much less weight in moderately moist air than in dry air.

Light

Appleman (2) found that potatoes exposed to light became green and had an increased respiratory activity. He believes this is due to a greater oxidation of the tissues by photosynthesis. This was especially true of immature tubers with slightly suberized skins.

The respiratory rate also varied with the stage of greening. Spoehr (33) in his studies on the effect of ionized air on respiration, disposes of potatoes in this connection with the statement: "For instance potato tubers evolve carbon dioxide so slowly that even with a large quantity, the differences between day and night are exceedingly slight."

Sprouting

The following are Appleman's (5) results on sprouting tubers: "Whole tubers of many varieties produce sprouts only from the buds on the seed end. Tubers of such varieties were cut in half and respiration measured separately in the seed and stem halves. It was found that respiration is always much higher in the seed halves when the sprouts are left on. This difference seems to be greater during incipitent sprouting than after the sprouts have attained considerable size. How much of the increased respiration in the seed ends, bearing the sprouts, is due to the respiration of the sprouts themselves is difficult to determine. If the sprouts are removed just prior to the measurement of respiration, the results are quite different and depend upon the variety in question. In all cases the difference in respiration between the seed and stem ends is suddenly reduced. In McCormick tubers, it always remains a little higher in the seed halves."

Influence of Carbon Dioxide and Oxygen Supply

Spoehr (33) in speaking of the effect of ionized air makes the statement: "We know, however, that the total rate of respiration is greatly influenced by the accumulation or removal of the end products of the first stages in the series. Even assuming, then, that the only function of the oxygen is the removal of these end products, as is maintained by many physiologists, the more rapid oxidation of these substances would result in an increased total rate, and hence increased total amount of carbon dioxide evolved." In his work on cacti (34) he finds that acid formation is benefited by the presence of oxygen. Richards (29) in his work on cacti found that the amount of carbon dioxide evolved (by the cactus) in normal air at 21° was about twice as great as that emitted in the absence of oxygen. At 30° the amounts were almost equal. Spoehr showed that cacti can live for at least five days in an atmosphere devoid of oxygen without any apparent injury.

Bennet and Bartholomew (l. c.) in their study on blackheart, find that injury in potato tubers due to the accumulation of carbon dioxide was most rapid at high temperatures. At low temperatures longer time was required. In one case tubers were exposed to an atmosphere devoid of oxygen for forty-two days at 50° before injury occurred. Injury at lower temperatures did not occur until the approximate equivalent of the available free oxygen had been returned as carbon dioxide to the atmosphere of the jar. The rate of respiration before exhaustion of free oxygen was about twice as great as afterwards. The tubers apparently used the oxygen accumulated in the tissues, but with more difficulty than the free oxygen from the surrounding atmosphere. In all cases, oxygen was absorbed more rapidly than carbon dioxide was produced during the early part of the experiments, and the respiratory ratio at the lower temperatures was less than at the higher temperatures.

Richards (30) found that injured potatoes placed in an atmosphere of reduced oxygen or one of hydrogen showed scarcely more respiration than normal tubers in air, from which he concludes that oxygen plays an important part in the reaction of the respiratory functions of a potato, to injury. He failed to find an increase in carbon dioxide evolution in an atmosphere of pure oxygen over the respiratory intensity in normal air, which shows that oxygen is not the only factor involved.

Butler (10 & 12) found that reducing the oxygen supply favors the accumulation of sugar. It was found that potatoes in dead air lost 7.61% less weight than did those stored in normal air for 90 days at 50°F and for 119 days they lost only 2.79% of their weight as compared to 17.24% for those stored in normal air. The degree of aeration needed will be greater the higher the temperature of storage.

Hass and Hill (18) quote Kidd as having determined that the sprouting of potato tubers is inhibited by an increase of 20% in the carbon dioxide content of the atmosphere. A higher concentration causes marked injury and ultimately death.

Intercellular Spaces and Gases

Richards (30) in 1896 roughly determined the amount of carbon dioxide held in the intercellular spaces and found it to be about 5 milograms per gram of substance. However, he did this by boiling the potato and collecting the carbon dioxide driven off, part of which might have been the decomposition product of the organic material, but he does not consider this probable as the gas was given off immediately on warming.

Bennet and Bartholomew (l. c.) consider that oxygen may be held within the tuber, attached to some autoxidizable substance such as peroxide, which accumulates during the early life of the tuber and is utilized in the more rapid respiration occurring in later stages, when stored under normal conditions. They found that this oxygen was apparently used up when the tubers were placed in an oxygen free atmosphere, and their tissues maintained in a normal state until the approximate equivalent of the oxygen originally available to the tubers (in jars) had been converted into carbon dioxide. Anerobic respiration was then necessary, which resulted in rapid injury to the tissues. They also came to the conclusion that oxygen is not evenly distributed throughout the tuber and consequently a deficiency will occur, usually at the point farthest from the source.

Magness (24) found the percentage of carbon dioxide in the gas within the tissues to increase markedly at the higher temperature with a corresponding decrease in oxygen. At low temperatures the total percentage of oxygen plus carbon dioxide was about equal to that of the air. At higher temperatures with decreasing oxygen in the tissues, the sum of the two increases, indicating that one molecule of oxygen liberates more than one molecule of carbon dioxide. This may be due to acid respiration as Gerber (15) thinks or to anerobic respiration because of a partial deficiency of oxygen. Considerable variation occurred in the gas content of potatoes held under identical conditions which is probably due to a wide variation in size, thickness of epidermis, etc.

Impermeability of the Periderm, Wounding and Surface Area

Hoffman and Sokolowskii (l. c.) found that small potatoes were stronger in respiratory activity than larger ones due to the difference in extent of surface exposed. They found that the amount of CO_2 evolved in twenty-four hours per kilogram of large, medium and small sized potatoes was 259,314 and 346 miligrams respectively.

In discussing their results on nitrogen and water content in relation to the intensity of respiration they state that the results might have been irregularly influenced by bacterial activities and resistances due to the character of the skin.

Stoward (36) found that the skin of undamaged tubers is, under ordinary conditions, impermeable to salts and acids in solution. This impermeability however is not possessed by blight infected tubers.

Wolfe (37) reports a definite correlation of the number of eyes with length, volume and weight of the tubers. The weight of tubers is apparently closely correlated in a positive manner with length, volume and weight of the tubers. The weight of tubers is apparently closely correlated in a positive manner with length, circumference width and thickness of tubers.

Boehm (9) mentions the fact that the respiration of potatoes effected with Phytophthora is above normal, which might be due either to injury or to the respiration of the organism or both together.

Richards (30) found a greatly increased respiration upon wounding which varied with the character of the tissues involved and the extent of the wounding. This increase in respiration reached its maximum in about two days and then declined, as the wound healed over, to a normal or almost normal rate. He attributes the increased respiration to a response on the part of the plant to recover from the injury, by which the ordinary functions of the plant are stimulated. He also found that in potatoes there was a certain amount of enclosed carbon dioxide which is given off very suddenly during the first two or three hours after injury, which seemingly indicates a higher respiratory intensity than in the hours which immediately follow.

Schneider-Orelli (31) found that wounding potatoes that were no longer capable of forming a wound periderm increases the amount of carbon-dioxide given off above that normally respired. He concludes therefore, that increased respiration is due to wounding alone and not to renewed cell division which follows wounding in tissues which are still capable of growth.

Butler (11) found that at temperatures from 8-10°, potatoes which were only slightly cut lost 2 to 3% more weight in 111 days than did uncut tubers which received the same treatment. The wounds healed much quicker at 20° than they did at 8 to 10°. He concludes with the statement: "Potatoes are apparently more sensitive to injury than would be anticipated from their general solidity."

Magness (l. c.) makes this statement, "It is apparent from these data that removing the epidermis greatly facilitates the entrance of oxygen to the tissues and also the escape of the accumulated carbon dioxide. It would be interesting to know to what extent increased respiration following wounding is due to mechanically facilitating this gaseous exchange, and to what extent it is due to actual metabolic changes in wounded tissues."

Appleman (2) states that "Immature potatoes have a thin, slightly suberized skin which is quite permeable to both water and gases. As the skin becomes suberized its permeability to water and gases is greatly reduced. The rapidity and degree of suberization is greatly influenced by moisture, dry conditions favor the process while moisture retards it." Again: "The amount of CO_2 expired from new potatoes with thin, slightly suberized skins is much greater than that from the same tubers after the skins have become well corked and adherent to the underlying tissue. Removal of the skin from mature tubers or hacking the entire surface of the tubers with a knife more than doubles the rate of respiration, which falls again with the formation of new thoroughly corked skin, to that of unpared tubers." These experiments would lead one to conclude that possibly the effect of anesthetics on respiration is really due to its effect on the permeability of the skin.

Denny (14) in a study of the permeability of plant membranes found that in general the increase in permeability per 10° rise in temperature varies from 1.3 to 1.8 or an average of about 1.5. These results are based on permeability to water but there appears to be no good reason why they would not hold for gases, since the process is a purely physical one.

Shapovalov and Edson (32) found that wound periderm is most effective near the edges of potatoes, in the center it is not nearly so well developed. Wounds received in loading should heal rapidly; wound periderm commencing to form in about six hours and at the end of two or three days is complete. They also make the statement that lenticles will not heal over except under very dry conditions or in case they are wounded. Artschwager (6) cites an instance in which a potato of the Bliss Triumph variety had its outer surface, including the lenticles, covered with hypertrophied cells. He also measured the thickness of the periderm on the commoner varieties of American potatoes.

In the recent work of Bennet and Bartholomew (l. c.) they arrived at the conclusion that the differences in the behavior of the different varieties at high temperatures may be due to a difference in the permeability of their skins to oxygen. All evidences point toward the permeability of the skin as an important factor affecting the rate of respiration of potato tubers.

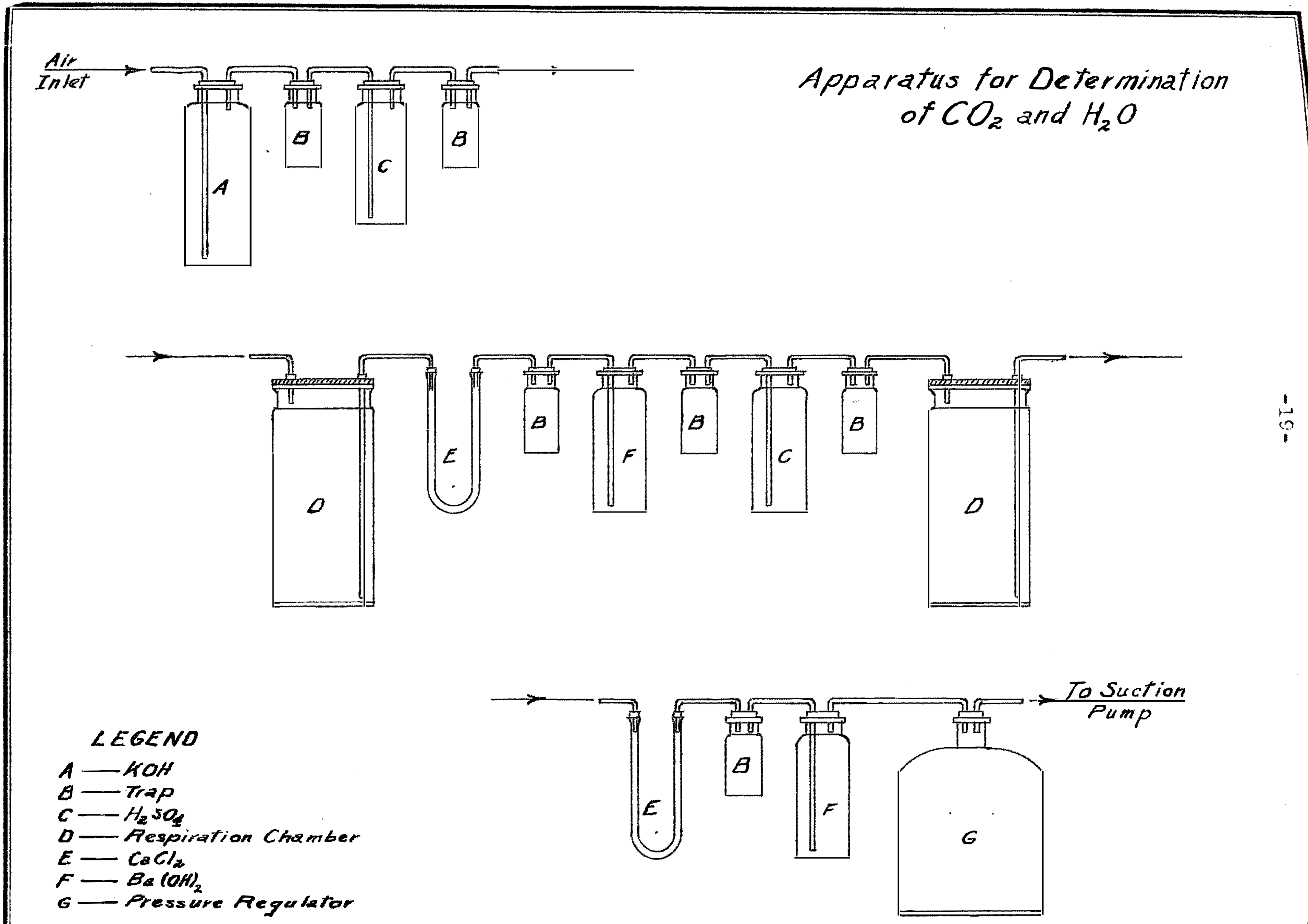
MATERIAL

The tubers used in this experiment were taken from the storage cellar as needed. Large, medium and small tubers were selected, the size of each group depending on the variety in question and not on a definite weight for each class. In fact the medium tubers of some varieties were larger than the large tubers of some of the other varieties. However, three distinct sizes were secured for each variety. This was done in order to determine the effect of surface area upon respiration and also because it was thought that the small tubers had approximately the same number of lenticles as the larger ones. Special pains were taken to secure clean, smooth, well developed tubers as free from disease or injury as possible. Only in one case was it necessary to use tubers which were even slightly infected with scab. Diseased tubers are undesirable because diseases tend to increase the permeability of the epidermis, conceal and possibly partially close the lenticles.

Very little attention was paid to the temperature at which the tubers had been stored, since the results desired did not depend on a normal rate of respiration.

Precautions were taken to see that the tubers showed no greening or sprouting and were not bruised. The first two of these factors act as stimulants to respiration while the bruises, if healed over, would tend to retard respiration since wound periderm is less permeable than the normal periderm. The tubers were not washed before being placed in the jars for fear of injuring the epidermis and the possibility of introducing some unknown variable factor.

After being sorted into the above mentioned groups, the tubers were placed in the jars as follows: two large tubers were placed in one jar, two or three medium sized ones in a second jar and three small ones in a third. A duplicate was then prepared for each jar and the six jars connected in series as shown in the plate.


Apparatus for Determination of CO_2 and H_2O
Air Inlet
A
B
C
B
D
E
B
F
B
C
B
D
To Suction Pump
E
B
F
G
LEGEND
A — KOH
B — Trap
C — H_2SO_4
D — Respiration Chamber
E — $CaCl_2$
F — $Ba(OH)_2$
G — Pressure Regulator

EXPLANATION

The completed circuit is as follows:

The entering air passes through the strong KOH solution in A which removes the CO_2 of the air, through trap B, through the H_2SO_4 in C which dries the air, then into the respiration chamber D. From here the air passed through the $CaCl_2$ tube E, which removed the moisture given off by the tubers, through trap B into the $Ba(OH)_2$ bottle where the CO_2 produced by the tubers was removed, through the next trap and into the H_2SO_4 in C which removed any moisture taken up by the air in passing through the $Ba(OH)_2$ solution, through the last trap and into the next respiration chamber. The procedure for the remainder of the series was the same. After passing through the last respiration chamber and its respective $CaCl_2$ tube and $Ba(OH)_2$ bottle, the air current passed through the pressure regulator G and out through the suction pump.

APPARATUS

The form of apparatus used in this experiment was based on the apparatus described by Spoehr (34) and also on that of Gore (17). It was set up in a dark chamber which had an average temperature of about 23°C. The temperature of this room never varied more than two or three degrees on either side of the mean.

The containers used as respiration chambers were museum jars of approximately 2.5 liters capacity. These jars had solid glass covers with no openings in them, so the covers had to be discarded and new ones made. For this purpose paper wall-board was used. A disc was cut the size of the top of the jar and another was cut so that it just fitted into the top of the jar. These two discs were then fastened together and holes bored in them for rubber stoppers through which glass tubing could be inserted. When the jars were in use the covers were sealed on by wrapping a paraffined strip of cloth at the joint between cover and jar and then coating the whole top of the jar with a mixture of paraffin and beeswax. The mixture of paraffin and beeswax was used because it was found that this mixture was more flexible than pure paraffin and less liable to crack under a slight strain. The writer does not recommend this method of covering the jars as it takes a great deal of time to obtain a perfect seal.

The sulphuric acid and Barium-hydroxide containers were 250cc wide mouth bottles, stoppered with rubber stoppers. The traps were six ounce wide mouth bottles also stoppered with rubber stoppers. Six inch U-tubes made of 5/8 inch tubing were used to hold the calcium chloride. The pressure regulator consisted of a large flask fitted with a rubber stopper through which two glass tubes had been inserted. A glass water pump was used throughout the experiment. Pure gum rubber tubing was used to make all connections between the ends of the glass tubing. The two glass tubes to be connected were abutted against each other as closely as possible so as to obtain a minimum exposure of rubber.

The air was drawn through the apparatus at approximately one-fourth liter per minute. Fluctuation in the amount of water flowing from the faucet to which the suction pump was attached caused this air current to vary somewhat. This should make very little difference in the rate of respiration as long as there is no accumulation of carbon dioxide in the respiration chamber and the carbon dioxide is completely absorbed by the barium hydroxide solution. In working with small quantities of wheat Spoehr (33) found that a variation in the rate of the air current from five-tenths to eight liters per hour caused no difference in the amount of carbon dioxide evolved.

PROCEDURE

When it was desired to run an experiment, the potatoes were secured from the storage cellar, sorted into groups, weighed, and placed in the respiration chambers and the jars sealed and tested. The sulphuric acid bottles were then filled and put in place. Next the U-tubes were filled with a weighed amount of calcium chloride and placed in the circuit. The last step was to fill the barium-hydroxide bottles and as rapidly as possible put them into place in order to avoid all unnecessary absorption of carbon dioxide from the air. The entire apparatus was then carefully sealed.

The first twenty-four hours results were always discarded, so as to be sure that the apparatus was free of carbon dioxide from the air. At the end of the experiment the tubers were again weighed to determine the loss in weight.

During the early part of the experiment the pressure regulator was not used and considerable difficulty was experienced with the solutions sucking back. For this reason the traps were installed. At first glance the trap between the sulphuric acid bottle and the respiration chamber does not appear necessary. However, it was found that when the bubbles produced by the air current broke they were often so close to the outlet that a small quantity of sulphuric acid was carried along with the air current. If a trap had not been present the acid might have come in contact with the potatoes and so greatly accelerated the rate of respiration. It was found necessary to renew the sulphuric acid every three days since by the end of that time it had become so dilute that it no longer absorbed all of the moisture.

A strong KOH solution was used for removing the carbon dioxide from the air as it entered since it could safely be used for an entire series of the experiment without being changed.

The barium hydroxide solution was made up to approximately 0.2 normal strength. This solution was made up in a quantity sufficient for the entire series of an experiment. One gram of barium chloride was added per liter. According to Spoehr (35) in order to secure accurate results it is necessary to add the barium chloride in order to suppress the hydrolysis of barium carbonate in the barium hydroxide solution. One hundred twenty five cubic centimeters of the solution was used in each of the bottles and was allowed to absorb the carbon dioxide evolved for a period of twenty-four hours. At the end of this time the solution was transferred to another bottle, tightly stoppered and set aside to allow the barium carbonate to settle. The bottles were washed, refilled and replaced as quickly as possible. Two 10cc portions of the supernatant solution was then titrated against 0.2 normal hydrochloric acid. In case a close check was not secured another 10cc portion of the clear solution was drawn off and titrated, thus avoiding the necessity of running triplicates for the entire series. The amount of the carbon dioxide evolved was calculated from the change in the concentration of the barium hydroxide solution.

The U-tubes were filled with freshly dehydrated calcium chloride every forty-eight hours. Twenty grams of calcium chloride was used in each tube. The tubes were weighed every twenty-four hours, at the time the barium hydroxide solution was changed, the difference in weight being considered due to the moisture given off by the tubers.

SURFACE AREA AND LENTICLE COUNTS

To be able to count the lenticles it was found necessary to boil the tubers, remove the epidermis, cut it into pieces approximately two centimeters square, place them on a moistened glass plate, and hold them up to the light. The lenticles could then be easily counted.

After counting the lenticles the pieces of skin were laid out on graph paper and their area estimated. Numerous attempts were made to measure the surface area by other methods but the irregularity in the shapes of the tubers prevented them from being at all accurate.

EXPERIMENTAL RESULTS

The results of the experiment have been compiled into two tables for each variety and a final set of tables has been added which gives the average results of all the varieties. The first table in each set gives the milligrams of carbon dioxide respired and the milligrams of moisture transpired per kilogram of tubers, the surface area in square centimeters per kilogram of tubers, the number of lenticles per square centimeter, the percent of weight lost and the number of tubers used in each case. It will be noted only a relatively small number of tubers were used in each case. Occasionally the various sizes overlapped. The second table in each set gives the milligrams of carbon dioxide respired, the milligrams of moisture transpired and the percent of weight lost per lenticle per kilogram of tubers. The second half of this table gives the same results figured per square centimeter of surface area. These figures reduce the factors involved to a common basis and allow them to be compared directly.

The results for moisture transpired are rather high and it is possible that the sulphuric acid did not remove all of the moisture from the air as it passed through it. However, the rate of the air current through each bottle was the same and the acid in all of the bottles was changed at the same time, so the results have been retained and are used only on a strictly comparative basis.

TABLE I

GREEN MOUNTAIN

Total results on Green Mountain potato tubers over a period of seven days.

Size	Number of Tubers	Percent of loss in weight	Milligrams H_2O per Kg. per hour	Milligrams CO_2 per Kg. per hour	Surface area in sq. cm. per Kg.	Lenticles per sq. cm.
Large	4	2.6	116.1	15.58	1321.08	2.86
Medium	6	3.02	104.4	14.99	1295. 81	3.55
Small	6	3.12	226.3	17.52	1687.40	3.24
Average		2.91	148.9	16.03	1434.76	3.22

TABLE II

Table showing milligrams CO_2, H_2O and the percent of weight lost per lenticle and per square centimeter of surface area, per kilogram of tubers, per hour.

	Average per Lenticle			Average per sq. cm. of Surface area		
Size	Milligrams CO	Milligrams H	% of Wt. lost	Milligrams CO	Milligrams H O	% of Wt. lost
Large	5.44	4059	0.91	0.0118	0.0879	0.00197
Medium	4.22	29.40	0.85	0.0116	0.0806	0.00233
Small	5.40	69.84	0.96	0.0104	0.1341	0.00185
Average	4.97	46.24	0.91	0.0112	0.1008	0.00205

GREEN MOUNTAIN

A glance at Table I shows only one uninterrupted rise from large to small sized tubers and that is in percent of weight lost, the average falling between the large and medium size. The medium sized tubers are the lowest in milligrams of CO_2 respired, in milligrams of H_2O transpired and in square centimeters of surface area per kilogram of tubers. The average in each case is between the large and small sized tubers. The number of lenticles per square centimeter of surface area proved to be highest for the medium sized tubers, the average lying between the large and small sized tubers.

The calculations per lenticle in Table II show the medium sized tubers to be lowest in all cases. The averages fall as follows:

Between the large and small sizes for H_2O transpired, between the medium and small sizes for CO_2 respired and coincides with that of the large size for percent of weight lost.

The calculation for milligrams CO_2 respired per square centimeter of surface area shows a gradual decline from large to small sized tubers with the average lying between the medium and small sized tubers. The milligrams of H_2O transpired have the lowest value for the medium size with the average falling between the large and small sizes. The medium sized tubers showed the highest percent of loss in weight with the average lying between the large and medium sizes.

TABLE V

IRISH COBBLER

Total results on Irish Cobbler potatoes over a period of seven days.

Size	Number of Tubers	Percent of loss in weight	Milligrams H O per Kg. per hpur	Milligrams CO per Kg. per hour	Surface area in sq. cm. per Kg.	Lenticles per sq. cm.
Large	4	0.87	161.89	15.75	1232.51	2.08
Medium	4	0.95	149.84	20.69	1391.17	2.8
Small	6	0.36	216.23	21.03	1701.94	3.19
Average		0.73	175.99	19.16	1441.87	2.69

TABLE VI

Table showing milligrams CO_2, H_2O and the percent of weight lost per lenticle and per square centimeter of surface area, per kilogram of tubers per hour.

	Average per Lenticle			Average per sq. cm. of Surface Area		
Size	Milligrams CO_2	Milligrams H_2O	% of Wt. lost	Milligrams CO_2	Milligrams H_2O	% of Wt. lost
Large	7.57	77.83	0.418	0.0128	0.1313	0.00706
Medium	7.38	53.51	0.339	0.0149	0.1077	0.00683
Small	6.59	67.78	0.112	0.0124	0.1270	0.00214
Average	7.12	65.42	0.271	0.0134	0.1220	0.00534

IRISH COBBLER

Table III shows a rise in milligrams CO_2 respired per kilogram per hour, in surface area per kilogram and in lenticles per square centimeter, the averages falling between the large and small sizes for the milligrams CO_2 respired and for lenticles per square centimeter. The average for the surface area falls between the medium and small sizes. The medium size is the lowest for milligrams H_2O transpired per kilogram, with the average between the large and the small sizes. Percent of weight lost is highest for the medium size, with the average lying between the medium and large sizes.

Table IV shows a decline in milligrams CO_2 respired per kilogram per lenticle and also in the percent of weight lost per lenticle, the average lying between the medium and small sized tubers. The medium sized tubers are the lowest in milligrams H_2O transpired per lenticle with the average falling between the small and medium sized tubers.

The milligrams CO_2 respired per square centimeter of surface area is highest for the medium size, the average being between the large and medium sized tubers. The milligrams H_2O per square centimeter is lowest for the medium size, with the average between the medium size, with the average between the medium and small sizes. The percent of weight lost per square centimeter of surface area shows a gradual decline between the large and medium sized tubers and then a sudden drop between the medium and small sized ones. The average lies between the medium and small.

TABLE V

BLISS TRIUMPH

Total results on Bliss Triumph potatoes over a period of seven days.

Size	Number of Tubers	Percent of loss in weight	Milligrams H_2O per Kg. per hour	Milligrams CO_2 per Kg. per hour	Surface area in sq. cm. per Kg.	Lenticles per sq. cm.
Large	4	1.43	158.9	27.21	1319.25	3.53
Medium	4	2.04	169.64	42.54	1367.76	2.98
Small	6	1.98	151.00	41.48	1632.54	2.90
Average		1.82	159.85	37.08	1439.85	3.14

TABLE VI

Tble showing milligrams CO_2, H_2O and the percent of weight lost per lenticle and per square centimeter of surface area, per kilogram of tubers per hour.

	Average per Lenticle			Average per sq. cm. of Surface Area		
Size	Milligrams CO_2	Milligrams H_2O	% of Wt. lost	Milligrams CO_2	Milligrams H_2O	% of Wt. lost
Large	7.7	45.01	0.405	0.0206	0.1204	0.00108
Medium	14 .27	56.8	0.677	0.0311	0.1240	0.00149
Small	14.3	52.1	0.682	0.0254	0.0925	0.00121
Average	11.8	50.9	0.579	0.0256	0.1123	0.00126

BLISS TRIUMPH

The medium sized tubers in Table V are the highest for milligrams CO_2 respired, milligrams H_2O transpired, percent of weight lost and number of lenticles per square centimeter. The averages fall as follows:

Between the large and small sized tubers, between the large and medium, between the small and medium and between the large and medium sized tubers respectively. The surface area shows a gradual rise from large to small sized tubers with the average falling between the medium and small sizes.

In Table VI there is a rise from large to small sized tubers in milligrams CO_2 respired and percent of weight lost per lenticle, with the average lying between the large and medium sized tubers in each case.

The medium sized tubers are highest in each case in the calculations per square centimeter of surface area. The averages for for the milligrams CO_2 respired per square centimeter and for percent of weight lost fall between the medium and small sized tubers. The average for the milligrams H_2O transpired per square centimeter falls between the large and small sizes.

TABLE VII

EARLY OHIO

Total results on Early Ohio potatoes over a period of seven days.

Size	Number of Tubers	Percent Of loss in weight	Milligrams H_2O per Kg. per hour	Milligrams CO_2 per Kg. per hour	Surface area in sq. cm. per Kg.	Lenticles per sq. cm.
Large	4	1.17	134.18	34.35	1161.95	2.35
Medium	4	1.21	141.42	42.66	1367.93	2.54
Small	6	1.58	214.84	58.02	1764.95	4.37
Average		1.32	163.48	45.01	1431.61	3.09

TABLE VIII

Talbe showing milligrams CO_2, H_2O and percent of weight lost per lenticle and per square centimeter of surface area, per kilogram of tubers per hour.

	Average per Lenticle			Average per sq. cm. of Surface Area		
Size	Milligrams CO_2	Milligrams H_2O	% of Wt. lost	Milligrams CO_2	Milligrams H_2O	% of Wt. lost
Large	14.61	57.09	0.498	0.0296	0.1155	0.00101
Medium	16.79	55.67	0.472	0.0312	0.1034	0.00088
Small	13.27	49.15	0.362	0.0329	0.1217	0.00090
Average	14.56	52.9	0.427	0.0310	0.1135	0.00093

EARLY OHIO

The results in Table VII show a steady rise from large to small sized tubers in every case with the average lying between the medium and small sized tubers in every case. This is the only variety of which this is true.

The calculations per lenticle in table VIII show a steady decline for the milligrams of H_2O transpired and percent of weight lost, but the rate of CO_2 emission is highest for the medium size. The averages for milligrams CO_2 respired and H_2O transpired per lenticle fall between the large and medium sized tubers but the average for percent of weight lost falls between the medium and small sizes.

The milligrams CO_2 respired per square centimeter show a steady rise from large to small sized tubers with the average between the medium and large sizes. The milligrams H_2O transpired per square centimeter is lowest for the medium size with the average falling between the small and large sized tubers. The percent of weight lost is least in the medium sized tubers with the average lying between the small and medium sizes.

TABLE IX

ALL VARIETIES

Total results on all of the four varieties of potatoes over a period of seven days.

Size	Number of Tubers	Percent of loss in weight	Milligrams H_2O per Kg. per hour	Milligrams CO_2 per Kg. per hour	Surface area in sq. cm. per Kg.	Lenticles per sq. cm.
Large	16	1.52	142.8	23.22	1258.69	2.71
Medium	18	1.81	141.32	30.22	1355.66	2.97
Small	24	1.76	202.09	34.51	1696.71	3.42
Average		1.70	162.07	29.32	1437.02	3.03

TABLE X

Table showing milligrams CO_2, H_2O and the percent of weight lost per lenticle and per square centimeter of surface area, per kilogram of tubers per hour.

	Average per Lenticle			Average per sq. cm. of Surface Area		
Size	Milligrams CO_2	Milligrams H_2O	% of Wt. lost	Milligrams CO_2	Milligrams H_2O	% of Wt. lost
Large	8.56	52.68	0.56	0.0184	0.1135	0.00121
Medium	10.17	44.21	0.61	0.0223	0.1042	0.00133
Small	10.09	59.09	0.51	0.0203	0.1191	0.00104
Average	9.67	53.48	0.55	0.0201	0.1123	0.00119

ALL VARIETIES

Tables IX and X are an average of the results of all of the varieties. Table IX shows a steady rise in the number of lenticles per square centimeter, surface area per kilogram, and milligrams CO_2 respired with the average of the average of the first two falling between the medium and small sized tubers and that of the last one falling between the large and medium sizes. The milligrams H_2O respired is low for the medium size with the average lying between the large and small sized tubers. The medium sized tubers are highest for percent of weight lost with the average between the large and small sizes.

The calculations per lenticle in Table X show no steady rise or decline. The milligrams CO_2 respired and the percent of weight lost per lenticle are highest for the medium sized tubers with the average lying between the large and small sizes. The milligrams H_2O transpired per lenticle is lowest for the medium sized tubers with the average between the large and small sizes.

The milligrams CO_2 respired and the percent of weight lost per square centimeter of surface area is highest in the medium size with the average falling between the medium and small sized tubers in the first case and between the large and small tubers in the last case. The milligrams H_2O transpired per square centimeter is lowest in the medium size, with the average lying between the medium and large sized tubers.

DISCUSSION OF RESULTS

When taken for each individual variety the results secured show no correlation between surface area, size, and number of lenticles in relation to respiration, transpiration and loss of weight. However, when the results are averaged a definite correlation is found to exist.

The following list shows the deviation from the average for each of the factors considered.

Milligrams CO_2 respired per lenticle.

The average shows the medium sized tubers to be the highest.

One variety shows a decline from large to small sized tubers--Irish Cobbler.

One variety shows a rise from large to small sized tubers--Bliss Triumph.

One variety shows the medium sized tubers to be the highest--Early Ohio.

One variety shows the medium sized tubers to be the lowest--Green Mountain.

Milligrams CO_2 per square centimeter.

The average shows the medium sized tubers to be the highest.

Two varieties show the medium sized tubers to be the highest--Bliss Triumph and Irish Cobbler.

One variety shows a decline from large to small sized tubers--Green Mountain.

One variety shows a rise from large to small sized tubers--Early Ohio.

Milligrams H_2O per lenticle.

The average of all varieties shows the medium sized tubers to be the lowest.

Two varieties show the medium sized tubers to be the lowest--Irish Cobbler and Green Mountain.

One variety shows the medium sized tubers to be the highest--Bliss Triumph.

One variety shows a decline from large to small sized tubers--Early Ohio.

Milligrams H_2O per square centimeter.

The average of all varieties shows the medium sized tubers to be the lowest.

Two varieties show the medium sized tubers to be the lowest--Irish Cobbler and Early Ohio.

One variety shows the medium sized tubers to be the highest--Bliss Triumph.

One variety shows a decline from large to small sized tubers--Green Mountain.

Percent of weight lost per lenticle.

The average of all varieties shows the medium sized tubers to be the highest.

Two varieties show a decline from large to small sized tubers--Irish Cobbler and Early Ohio.

One variety shows a rise from large to small sized tubers--Bliss Triumph.

One variety shows the medium sized tubers to be the lowest--Green Mountain.

Percent of weight lost per square centimeter.

The average of all varieties shows the medium sized tubers to be the highest.

Two varieties show a decline from large to small sized tubers--Irish Cobbler and Bliss Triumph.

One variety shows the medium sized tubers to be the highest--

Green Mountain.

One variety shows the medium sized tubers to be the lowest--Early Ohio.

Milligrams CO_2 per lenticle per kilogram per hour.

The above list shows no particular correlation or prevailing condition to exist between the milligrams of CO_2 respired and the number of lenticles per square centimeter for individual varieties, but the average indicates that the medium sized tubers respired the most CO_2 per lenticle.

The Green Mountain tubers were slightly infected with scab which may account for any variation from the average as far as they are concerned. The following description of the disease taken from Harshberger (19) explains why this might be true. "The first symptoms of the disease are minute reddish-brown spots on the surface of the tuber beginning usually at one of the lenticles of the tuber and spreading rapidly to other tissues, assuming a deeper color and an abnormal corky development over considerable areas. Thus arise the scab-like crusts which have given the common name to the disease. The surface of the tuber frequently becomes cracked to a considerable depth."

The Early Ohio tubers which were in perfect condition are in accord with the average.

These results indicate that medium sized tubers respire at a greater rate per lenticle than do tubers that are either larger or smaller. This might be explained by the fact that the medium sized tubers have all lenticles fully developed, which is not true of small tubers, and that the storage tissue is in the right proportion to the lenticles to give the proper amount of aeration to the tissues with a consequently high rate of respiration.

Milligrams CO_2 per square centimeter.

The average of the milligrams CO_2 respired per square centimeter agrees with the milligrams CO_2 respired per lenticle in that it is the highest in the medium sized tubers. In this case the results for the individual varieties correspond much closer to the average than do the results per lenticle. The Bliss Triumph and Irish Cobbler varieties show the respiration of the medium sized tubers to be highest per square centimeter. The Green Mountain variety shows a steady decline from large to small and the Early Ohio variety shows a steady rise from large to small sized tubers.

The fact that the calculations for milligrams CO_2 respired per lenticle and the milligrams CO_2 respired per square centimeter agree in placing the medium sized tubers as being the highest producers of carbon dioxide per unit, indicates a definite correlation between the number of lenticles and the surface area in relation to respiration. This is to be expected if the major portion of the gas interchange takes place through the lenticles and the results show that it does.

Moisture transpired per lenticle and per square centimeter of surface area.

The average of all varieties shows the milligrams of moisture transpired per lenticle to be lowest for the medium sized tubers. Two varieties, the Irish Cobbler and Green Mountain, are in accord with this average. The Bliss Triumph variety shows the medium sized tubers to be the highest, while the Early Ohio variety shows a steady decline from large to small sized tubers in milligrams H_2O transpired per lenticle.

The milligrams H_2O transpired per square centimeter of surface area agrees perfectly with the milligrams H_2O transpired per lenticle. This strengthens the correlation between the number of lenticles and surface area.

It seems strange that the tubers with the highest rate of CO_2 emission should have the lowest rate of moisture transpired. If the rate of CO_2 respired is high there should also be a high rate of moisture transpired if the moisture transpired is chiefly due to the breaking down of carbohydrates. That the major portion of this moisture lost is not due to this cause is at once apparent from the results.

There is a possibility that under ordinary atmospheric conditions, large tubers may retain more moisture within the intercellular spaces than do the medium sized ones and that when these tubers are placed in a current of dry air this excess moisture is removed giving them what seems to be a high rate of transpiration. In the case of small tubers with their large exposure of surface in proportion to storage tissue there would naturally be a rapid dessication in a current of dry air. Whether or not these conditions exist would have to be determined by running moisture tests on the different sized tubers before and after conducting the experiment.

<u>The percent of weight lost per lenticle and per square centimeter of surface area</u>.

According to the average, the medium sized tubers appear to be the highest in percent of weight lost per lenticle. The individual varieties do not agree with the average in this respect. The Irish Cobbler and Early Ohio varieties show a decline in percent of weight lost per lenticle from large to small sized tubers. The Green

Mountain variety shows the medium size to be the lowest and the Bliss Triumph variety shows a steady rise from large to small in the percent of weight lost per lenticle.

On the basis of the percent of weight lost per square centimeter of surface area, the average shows the medium sized tubers to be the highest which agrees with the average for percent of weight lost per lenticle. The individual varieties show very little agreement with this average. The Bliss Triumph and Irish Cobbler varieties show a decline in percent of weight lost from large to small sized tubers, while the Green Mountain variety shows the medium size to have had the highest percent of weight lost per square centimeter of surface. The Early Ohio variety shows the medium size to have had the lowest percent of loss in weight per square centimeter.

These results indicate that the loss in weight of potato tubers is due to the consumption of the carbohydrates rather than to a loss of moisture. The medium sized tubers had the highest rate of carbon dioxide respiration and the highest percent of weight lost yet they had the lowest amount of moisture transpired, therefore the loss in weight must be due to the consumption of the stored food.

CONCLUSION

The results obtained in this investigation show a definite correlation to exist between the number of lenticles and the surface area in relation to the amount of carbon dioxide respired, moisture transpired and the percent of weight lost.

The medium sized tubers are the highest in milligrams carbon dioxide respired, lowest in milligrams of moisture transpired and highest in the percent of weight lost. The high rate of carbon dioxide respiration in medium sized tubers is probably due to the fact that the storage tissue of the tuber is in the proper proportion to the number of lenticles and the surface area to secure thorough aeration of the tissues. The only reason that can be given for the small tubers not respiring as much as the medium sized ones is that the periderm was less permeable. The writer believes that the lenticles, although more numerous on small tubers, in proportion to area and weight, are probably not fully developed and therefore does not permit the easy interchange of gases that occurs in the medium size tuber with its fully developed lenticles. The low rate of moisture transpired by the medium sized tubers is apparently due to the fact that under normal atmospheric conditions they do not contain an excess of moisture in the intercellular spaces as do large ones and consequently do not lose as large an amount of moisture when placed in a current of dry air. The small tubers probably lost more moisture than the medium sized ones due to dessication, which took place through both the lenticles and the epidermis, and which would be greatest in the small tubers because of the relatively large surface exposure. The higher rate of loss in weight for the medium sized tubers is accounted for by the fact that loss in weight of potato tubers is due to carbohydrate consumption and not to the moisture lost.

SUMMARY

1. A definite correlation exists between the number of lenticles and the surface area of a potato tuber as regards respiration, moisture transpired and the percent of weight lost per kilogram per hour
2. The medium sized tubers show the highest rate of carbon dioxide respired per lenticle and per square centimeter of surface area per kilogram per hour.

3. The medium sized tubers are lowest in respect to the milligrams of moisture transpired per lenticle and per square centimeter of surface area per kilogram per hour.

4. The medium sized tubers show the highest percent of loss per lenticle and per square centimeter of surface area per kilogram per hour.

5. The individual varieties deviated considerably from the average in every respect. The results obtained for the Early Ohio variety are closer to the average results than are the results of any other variety.

6. The loss in weight of the tubers is apparently due to the consumption of carbohydrates and not to the moisture lost.

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