THE RESPIRATION FACTOR IN THE DETERIORATION OF FRESH VEGETABLES AT ROOM TEMPERATURE[1]

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INTRODUCTION

The physiological changes that occur during the rest period of the hardy vegetables have been the subject of many investigations. In general, the chemical composition varies slowly, and it has been found convenient to allow rather large intervals of time to elapse between observations. Among the more perishable vegetables, however, Morse,[2] working with asparagus, and Appleman,[3] and Appleman and Arthur,[4] with green sweet corn, have found that profound changes in composition occur within a few hours after harvesting, sweet corn, for instance, losing between 50 and 60 per cent of its sugar during 24 hours at 30° C., and very little after that with longer holding; by using a low storage temperature the loss could be very appreciably reduced. In view of the manner in which fresh vegetables are usually handled in markets, stores, and kitchens it becomes important to investigate the changes occurring at room temperature in other green vegetables during the first few hours after they are gathered, and that was the object of the present study. As respiration is probably the principal factor in the deterioration of fresh vegetables at higher temperatures, attention was focused upon that process.

It is recognized that vegetables in markets and stores are subjected to many variables, all of which probably affect the rate of respiration and the rates of the other processes involved in deterioration; there are external variables such as temperature, humidity, and intensity and kind of illumination, and internal factors involving the variety of the vegetable and its degree of maturity. It would be interesting to determine the influence of each of these variables on the rate of respiration, but that was beyond the scope of this study, and so fixed conditions were chosen—a temperature of 30° C., an atmosphere which was saturated with water vapor, absence of light, and that stage of maturity in each case which represents prime eating condition—and the data obtained from the different vegetables under identical conditions should serve as the basis for comparisons.

EXPERIMENTAL PROCEDURE

A diagram of the apparatus used in the experiments is shown in Figure 1. Soda lime in A served to remove CO_2 from the air that entered from out of doors. The reservoir C and the respiration

[1] Received for publication Feb. 11, 1929; issued July, 1929. Published with the permission of the director of the station.

[2] MORSE, F. W. EXPERIMENTS IN KEEPING ASPARAGUS AFTER CUTTING. Mass. Agr. Expt. Sta. Bul. 172, p. [297]-307. 1917.

[3] APPLEMAN, C. O. RESPIRATION AND CATALASE ACTIVITY IN SWEET CORN. Amer. Jour. Bot. 5: 207-269, illus. 1918.

[4] ——— and ARTHUR, J. M. CARBOHYDRATE METABOLISM IN GREEN SWEET CORN DURING STORAGE AT DIFFERENT TEMPERATURES. Jour. Agr. Research 17: 137-152, illus. 1919.

chamber D were placed beneath the surface of the water in an electrically controlled thermostat. It was assumed that the movement through C would be sufficiently slow to allow the air to assume the temperature of the surrounding bath and become very nearly saturated with water vapor from the layer of water in the bottom of this 2-liter bottle; a dropping funnel (not shown) permitted the addition of more water in C as it was needed. The air was always sufficiently humid to prevent the vegetables from wilting. For the respiration chamber,

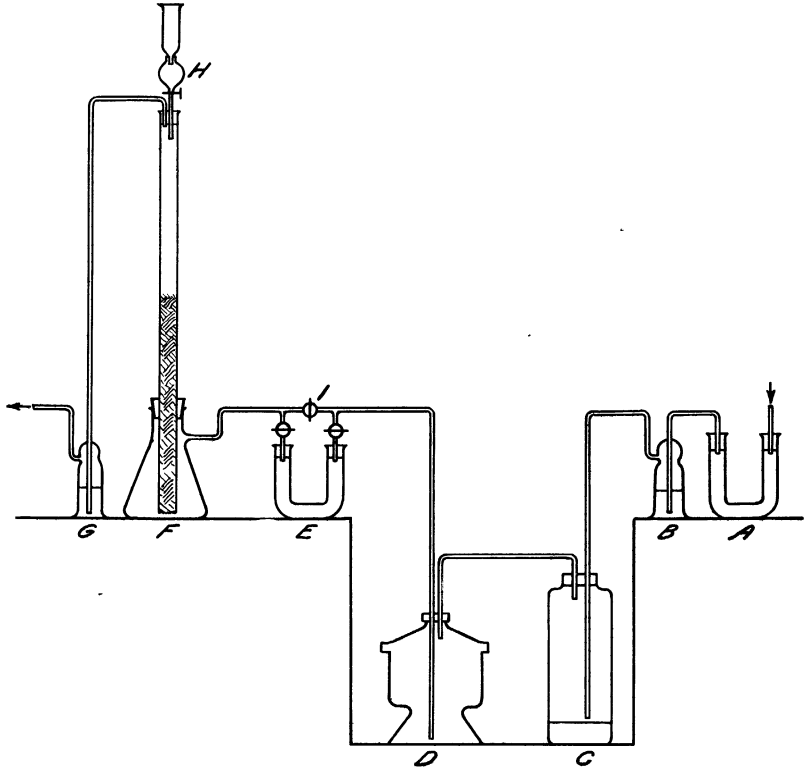

FIGURE 1.—Diagram of the respiration apparatus: A and E contain soda lime; B and G contain a dilute solution of bromthymol blue; C, air reservoir; D, respiration chamber; F, Truog absorption tower; H, 50 c. c. separatory funnel for introducing standard $Ba(OH)_2$ solution; I, stopcock. C and D are placed in the constant temperature bath

vessels of various sizes and shapes were used, the object being to suit the vessel to the vegetable so as to allow as little waste space as possible—wide-mouthed bottles, small desiccators, and sometimes straight tubes 1-inch in diameter, stoppered at each end, served the purpose. The stopcocks at I permitted the gases to be diverted through the soda-lime tube E between measurements. F is the Truog [5] absorption tower with the tube lengthened to 30 inches to lessen the danger of loss of solution at the top. $Ba(OH)_2$ solution was introduced at H. Truog's technic was followed almost exactly in the use of this tower, which proved to be much more efficient than

[5] TRUOG, E. METHODS FOR THE DETERMINATION OF CARBON DIOXIDE AND A NEW FORM OF ABSORPTION TOWER ADAPTED TO THE TITRIMETRIC METHOD. Jour. Indus. and Engin. Chem. 7: 1045-1049, illus. 1915

any other absorption device tested. At B and G small wash bottles were introduced containing a dilute solution of bromthymol blue. The laboratory distilled water had a pH of approximately 8.0 when CO_2 was removed and consequently gave a good deep-blue color with this indicator. The wash bottles, situated as they were, served to show whether CO_2 entered C or escaped from F. On a few determinations with asparagus (the most rapidly respiring vegetable examined) a small white crucible containing a little of the indicator was placed in the respiration chamber D with the vegetable, and gave assurance by its green tint that the rate of movement of the gas stream was sufficiently rapid to prevent the collection of significant amounts of CO_2 in the chamber. In making determinations the water pump was turned on far enough to draw bubbles almost to the top of F, and the indicator bottles were watched to see that they maintained the proper shade; beyond this no attempts were made to measure or control the rate of flow of gases through the train. Sometimes preliminary experiments were necessary to discover the most convenient amount of any vegetable to use; the weights employed varied from 50 to 500 gm. The respiration chamber was submerged beneath approximately a foot of water, in most cases lead plates covered the top to keep it down, and the thermostat was in a corner of the laboratory far removed from windows, so that the influence of light may be considered negligible.

Experimental material consisted of fresh vegetables of edible maturity brought directly from the garden into the laboratory before the sun was high enough to cause any wilting. All unnecessary bruising was avoided. Vegetables were used for study in the forms in which they are displayed on the market; that is, in the case of beet, green onion, carrot, and lettuce, the whole plant was used; in the case of green beans, pimientos, mangoes, and okra, a very short stem was left attached; tomatoes were pulled off carefully from the vine, and asparagus was cut at the surface of the soil. The choice of vegetables was determined by availability. It should be noted that the temperature in the garden when the vegetables were obtained was usually near 30° C., so that the material was not subjected to a decided change in temperature when it was placed in the thermostat. The material was washed, dried carefully, and weighed, only perfect specimens being used.

Thirty degrees centigrade was chosen as the working temperature and the bath was held constant to within $\pm 0.5°$. This particular temperature seemed best adapted to the study for two reasons—(1) it was practically the lowest temperature which could be held constant during the summer months with a water thermostat and no special cooling device, and (2) it represents fairly well the average daytime room temperature in this part of the country (Oklahoma).

Determinations were made as follows: After the material for study had been placed in the respiration chamber D, 25 c. c. of 0.25N Ba $(OH)_2$ was introduced into the funnel H, and the suction of air through the apparatus was begun, the by-pass tube E being used to remove all CO_2 coming from the respiration chamber. When the indicator bottle showed by its color that the CO_2 originally present in the absorption tower had been removed (usually about one-half hour sufficed) the stopcock in H was opened, allowing the $Ba(OH)_2$ solution to enter the tower. The stopcock of H was closed immedi-

ately and the stopcock I opened, at the same time the two stopcocks on the by-pass tube were closed. The exact time of opening I was noted; the runs were continued for exactly one hour, after which I was again closed, the by-pass stopcocks opened, and the suction reduced. The $Ba(OH)_2$ solution remaining on the walls of H was washed into the absorption tower F with small amounts of CO_2=free water. The absorption apparatus was disconnected, the stopper carrying the tube loosened, and the beads washed with CO_2=free water into the flask, where the excess $Ba(OH)_2$ was determined by titrating with N/10 HCl in the presence of phenolphthalein. Determinations were repeated at 2-hour intervals throughout the day. The experimental material was kept in the thermostat overnight, but the lid of the respiration chamber was replaced by a loosely arranged wet cloth and the jar was supported with its mouth on a level with the surface of the water, so as to allow free access of air to the vegetables without allowing them to wilt or change temperature. Determinations were continued then through the second day. Blank determinations showed that no measurable amount of CO_2 leaked in or was taken up directly during the manipulations.

EXPERIMENTAL RESULTS

The results, presented in the form of curves, are shown in Figure 2. In every case where there was a significant decline in the rate of respiration during the first 12 hours the whole 30-hour determination was repeated one or more times with fresh material. The curve given in each case was one chosen as typical. Curves on different specimens of the same kind of vegetable were always closely similar in shape and in actual position. The curves appear to approach the logarithmic in form. By mechanically computing the area under the curves for a 24-hour period (from the second until the twenty-sixth hour) the total amount of CO_2 evolved was determined; by assuming that all the carbon lost came from glucose, the weight of this sugar used up may also be calculated. These values are shown in Table 1.

TABLE 1.—*Calculations of the carbon and glucose lost per 100 gm. dry weight of various vegetables when held at 30 C° for 26 hours after cutting*

Vegetable	Dry matter	Weight of CO_2 evolved between second and twenty-sixth hour	Weight of carbon lost between second and twenty-sixth hour	Calculated weight of glucose lost between second and twenty-sixth hour
	Per cent	*Grams*	*Grams*	*Grams*
Asparagus	8.3	20.066	5.473	13.682
Lettuce	6.2	9.424	2.570	6.425
Green beans	7.7	9.273	2.529	6.322
Okra	13.7	7.699	2.091	5.228
Green onion	9.3	6.627	1.807	4.518
Carrot	13.9	4.659	1.271	3.178
Tomato	6.1	3.920	1.069	2.672
Beet	9.5	[a] 2.958	.807	2.018
Green mango (sweet pepper)	8.0	2.880	.758	1.962
Red pimiento (short, broad variety)	9.4	1.893	.516	1.290

[a] It was only possible to carry the beet determinations over the first day because of a tendency to mold. The values here given were obtained by extrapolation.

No more need be said about the order of the vegetables with respect to the amount of CO_2 evolved than that it is in agreement with the general observation that the most rapidly developing tissue respires

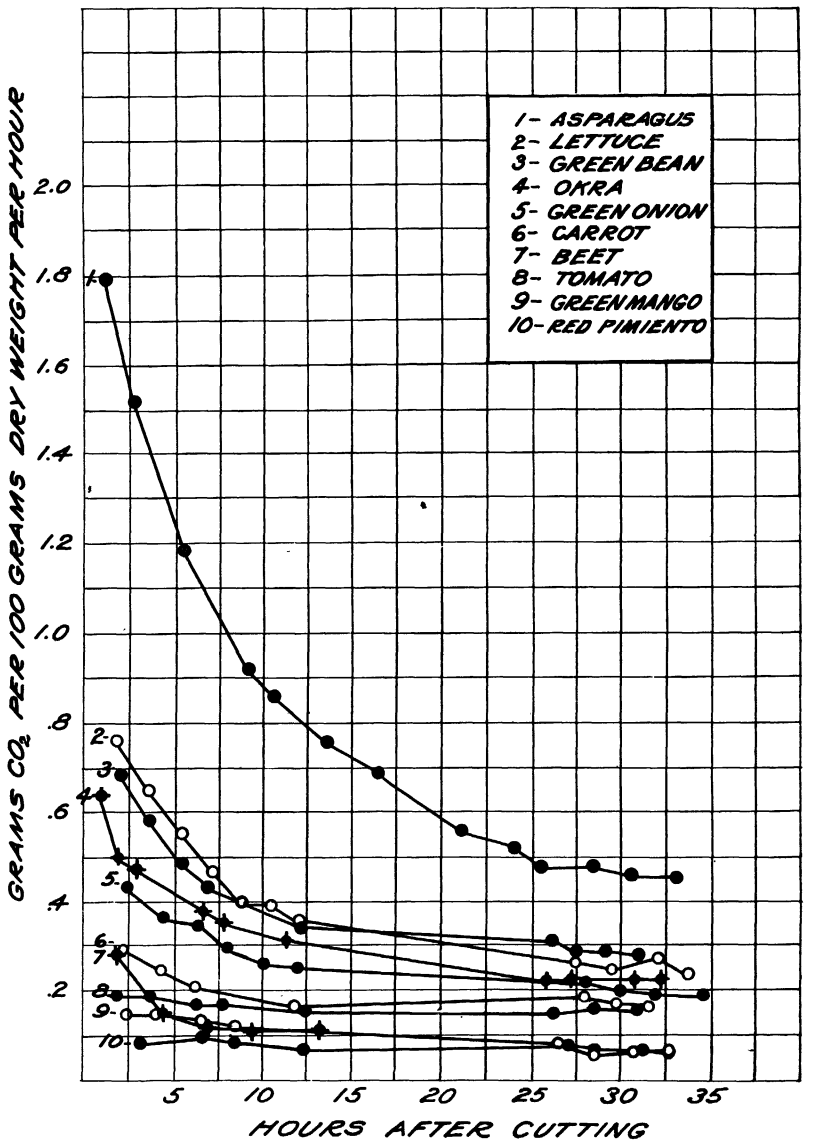

FIGURE 2.—Curves showing decline in respiration rate of fresh vegetables during the first 30 hours after cutting, when held at a constant temperature of 30° C. (±0.5)

most rapidly. That other significant changes, tending to decrease the food value of the vegetables under consideration, were occurring simultaneously is not to be doubted, such as, for example, an increase

in woody fiber.[6] This study presents only one phase—although probably the principal one—of the general deterioration process.

The vegetables came out of the thermostat (except the beet) after one and one-half days at 30° C., in an atmosphere nearly saturated with water vapor, looking as fresh and attractive as if they were straight from the garden—there was no outward indication of the changes which had gone on, except that the asparagus had increased a little in length.

SUMMARY

Ten green vegetables of edible maturity were subjected to comparative examination during the first 30 hours after they were harvested. Their changing rates of respiration at 30° C. were measured and plotted, the total amount of CO_2 evolved between the second and the twenty-sixth hours was calculated and the weights of glucose presumably oxidized in producing this quantity of CO_2 were computed. With respect to the amount of gas evolved for equal weights of dry matter during the 24-hour period, the vegetables stand in the following descending order: Asparagus, lettuce, green bean, okra, green onion, carrot, tomato, beet, green mango, red pimiento. The amounts of glucose accounted for vary from 13.682 gm. per hundred grams of dry weight in 24 hours for asparagus to 1.290 gm. for red pimientos.

[6] BITTING, K. G. DETERIORATION IN ASPARAGUS. Natl. Canners Assoc. Research Bul. 11, 18 p., illus. 1917.