VEGETABLE STORAGE

Respiration of Vegetables as Affected By Postharvest Treatment

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The carbon dioxide production of tomatoes, lima beans, snap beans, sweet corn, peas, and asparagus was measured over a 7-day storage period at temperatures of 32°, 38°, 44°, and 72° F. Carbon dioxide production increased rapidly with rise in temperature; the rate at 44° F. was approximately double that at 32° F. for sweet corn, peas, and lima beans. The increase in this range for snap beans, asparagus, and tomatoes was from 62 to 79%. Husking sweet corn or cutting snap beans had little effect on carbon dioxide production, while the shelling of peas and lima beans greatly increased respiration. Not only do the carbon dioxide production rates of vegetables vary widely but the respiratory response to temperature increases and to wounding or exposure during preparation for marketing may be entirely different for various vegetables.

New methods employed in the transportation, storage, and packaging of fresh vegetables have presented problems concerned with the physiological processes taking place in the fruit or other plant parts between time of harvest and consumer use. The storage behavior of fresh vegetables prepared for "prepackaging" or "consumer packaging" is of especial interest at this time. Consumer packaging together with cold storage handling after harvest is designed in part to improve the quality of produce offered to the consumer. The respiratory studies presented in this paper were undertaken to provide a basis for further work on the physiological factors affecting the quality of fresh vegetables during the postharvest period. Data are given on rates of carbon dioxide production by vegetables after harvest, with particular emphasis on the activity during low temperature storage, and the effect of method of preparation of certain vegetables for consumer packaging upon carbon dioxide production. For the purpose of this paper, carbon dioxide production is considered as a measure of respiratory rate.

Although there have been a number of reports on the effect of temperature on the respiratory rates of plant materials, there is little information on the respiratory behavior of economic vegetable crops held at low temperatures.

Platenius (*6*) gave respiration rates of ten vegetables held at 0.5°, 10°, and 24° C., and stated that the $Q10$ values for the lower temperature range were generally higher than those of the upper range. Temperatures of interest in the commercial application of cold storage of vegetables would fall in the lower range. Pentzer and coworkers (*5*) reported respiratory rates of asparagus at temperatures of 32°, 40°, 50°, and 70° F., which are in close agreement with rates found in the present study.

Preparation of vegetables for consumer packing frequently involves wounding of the tissues and exposure of tissues which are normally protected in conventional handling procedures. The stimulatory effect of wounding upon carbon dioxide of plant tissues has been demonstrated by Richards (7), Hopkins (*3*), and Appleman and Brown (*1*). The effect of the exposure of certain plant tissues on respiration, such as occurs with the shelling of peas or lima beans, has received little attention.

Materials and Methods

The vegetables used in the tests were produced from plants grown on the University of Maryland Plant Research Farm. They were harvested at the optimum stage of maturity for fresh consumption, and with sufficient care to prevent unnecessary injury. Harvesting was done in the early morning and the material was prepared and placed in the respiration chambers within the shortest possible time, usually less than 3 hours. Representative samples, uniform as to degree of maturity, size, and number, were selected.

The varieties of vegetables were: Mary Washington asparagus, Alaska peas, Black Valentine snap beans, Marglobe tomatoes, Country Gentleman sweet corn, and Peerless lima beans. The weights of the samples used in the respiration chambers approximated 200 grams for asparagus, peas, snap beans, and shelled lima beans; 400 grams for pod lima beans; and 800 grams for tomatoes and sweet corn.

The asparagus stalks were green tips trimmed to 6 inches. Snap beans were picked by hand and samples sectioned were cut with a sharp knife. The tomatoes were of uniform pink color and size, with the stems removed. Five fruits constituted a sample. The sweet corn samples consisted of three ears. In the treatments involving husked ears, the husks were removed by hand. The samples of shelled peas and lima beans were picked from the vines by hand.

The respiration chambers were 12-inch glass desiccators provided with a tubulature in the lid for access lines. Sixteen chambers were used, four in each of four constant temperature cabinets installed in a refrigerated room held at 25° F. The cabinets were maintained at 32°, 38°, 44°, and 72° F. by thermostatically controlled electric elements. Control was within ±0.5° F. The respiration chambers were connected to absorption towers placed in the laboratory outside of the refrigerated room.

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Table I. Respiratory Rates of Certain Vegetables During Storage at Different Temperatures

(Expressed as mg. of CO_2 per kg. per hour on fresh weight basis)

Storage Temp., ° F.	Days of Storage 1	2	3	4	5	6	7	Mean of 6 or 7 Days
				Tomatoes				
32	...	14.9	...	9.4	...	5.6	...	10.0
44	...	26.5	...	15.7	...	11.4	...	17.9
72	...	57.2	...	55.4	...	40.8	...	51.1
				Snap Beans				
32	33.6	40.9	31.8	29.3	30.7	25.6	28.1	31.4
38	32.1	46.9	36.4	36.7	33.8	32.7	40.7	37.0
44	53.3	46.9	55.4	36.1	59.7	52.0	53.5	51.0
72	206.0	200.8	192.8	166.6	180.8	154.6	175.8	182.5
				Asparagus				
32	80.4	41.6	41.8	38.2	32.0	43.4	42.1	45.6
38	88.1	63.0	48.2	46.1	37.7	37.7	37.2	51.1
44	128.8	93.5	72.3	66.3	74.7	70.0	59.4	80.7
72	309.5	252.6	252.1	...	...	...	...	271.4
				Lima Beans (Pod)				
32	...	29.9	...	20.1	...	17.6	...	22.5
38	...	35.9	...	28.9	...	26.4	...	30.4
44	...	52.8	...	51.5	...	48.6	...	51.0
72	...	178.9	...	...	...	139.2	...	159.1
				Lima Beans (Shelled)				
32	...	34.8	...	20.3	...	17.6	...	22.5
38	...	60.8	...	41.2	...	29.1	...	43.7
44	...	106.0	...	75.8	...	90.6	...	90.8
72	...	265.4	...	211.5	...	250.3	...	242.4
				Sweet Corn (in Husk)				
32	51.3	36.8	36.1	30.8	32.7	32.7	39.2	37.1
38	60.2	50.3	52.8	51.9	48.3	48.3	55.4	52.5
44	93.4	88.7	81.7	70.8	60.3	60.3	50.3	72.2
72	310.8	496.6	307.6	246.0	238.3	238.3	287.5	303.6
				Sweet Corn (Husked)				
32	56.1	40.4	39.1	34.2	37.6	37.6	39.5	40.7
38	53.3	53.6	54.1	55.0	53.9	53.9	56.3	55.7
44	83.1	101.1	114.4	80.1	66.0	66.0	62.5	81.9
72	354.8	437.5	253.5	223.0	217.1	217.1	165.5	266.9
				Peas (Pod)				
32	38.7	39.8	30.5	46.1	46.9	46.1	45.3	41.9
38	55.1	65.1	60.8	65.0	76.4	69.0	65.8	65.3
44	72.1	76.1	84.8	65.8	82.8	93.3	78.2	78.9
72	295.5	306.9	361.5	323.3	313.0	297.4	245.5	306.2
				Peas (Shelled)				
32	75.6	66.1	65.3	70.3	47.1	57.9	51.9	62.0
38	97.4	94.9	90.3	79.0	86.4	85.9	95.1	89.9
44	118.1	102.7	100.3	111.1	158.3	251.9	210.3	136.1
72	395.7	348.6	354.8	428.4	556.5	423.8	417.9	418.0

The absorption apparatus was similar to that first described by Gore (*2*) and later used with some modifications by Kimbrough (*4*) and Appleman and Brown (*1*). The flow of air through the respiration chambers and absorption columns was maintained with a vacuum pump and adjusted to a rate of 80 to 100 ml. per minute.

Humidity in the respiration chambers was maintained close to saturation by placing several hundred milliliters of water in the desiccators. All respiration runs were made in duplicate.

The amount of carbon dioxide produced was measured daily except in the case of the tomato and lima bean samples, when measurement was made at 2-day intervals. The respiration runs were continued for as long as 14 days with certain of the vegetables, but the data presented represent a 7-day storage period, since such a duration was considered commercially practicable for the vegetables used.

Results

The respiratory rates of the several vegetables during the storage period, expressed as milligrams of carbon dioxide per kilogram of fresh weight per hour, are given in Table I. With all samples except peas, the respiratory rate tended to decrease during the storage period. Wide differences in respiratory rate among the vegetables tested were observed—for example, asparagus, sweet corn, and peas showed roughly four times as great carbon dioxide production as tomatoes. Snap beans and lima beans were in an intermediate position. An increase in storage temperature was accompanied in all instances by an increase in rate of respiration. That this effect of temperature varied with the different types of vegetables is shown in Table II. Increasing temperature from 32° to 38° F. caused a 12.1% increase in carbon dioxide production of asparagus but an 80.6% increase for shelled lima beans. With asparagus, snap beans, and lima beans the increase in carbon dioxide production associated with rise in temperature from 38° to 44° F. was more pronounced than that occasioned by rise in temperature from 32° to 38° F.

The carbon dioxide production of husked sweet corn, shelled peas, and pod and shelled lima beans more than doubled with the 12° F. rise in temperature from 32° to 44° F.

The respiratory rates of sweet corn in the husk were very similar to those of husked ears. On the other hand, the rate of respiration for shelled lima beans or peas was markedly higher than for these vegetables in the pod. The effect of husking sweet corn and shelling lima beans on respiration is given in Table III. In this test, carbon dioxide production of husked ears and the separated husks was compared with that of the intact ear. Similarly, the carbon dioxide production of seeds and shells of lima beans was measured in comparison with that of the corresponding weight of intact pods. The combined carbon dioxide production of the two portions of the sweet corn ear only slightly exceeds that of the whole ear. However, the combined carbon dioxide production of the two portions of the seeds and pods of lima beans is more than double that of the intact pods. It is apparent that the wounding and exposure occasioned by the shelling process greatly increased the carbon

Table II. Increase in Respiratory Rate of Vegetables with Increase in Storage Temperature

(Calculated on percentage basis)

Vegetable	32° to 38° F.	38° to 44° F.	32° to 44° F.
Snap bean	17.8	37.8	62.4
Asparagus	12.1	57.9	77.0
Sweet corn (in husk)	41.5	37.5	94.6
Sweet corn (husked)	36.9	47.0	101.2
Peas (pod)	55.8	20.5	88.3
Peas (shelled)	45.0	51.4	119.5
Lima beans (pod)	35.1	67.8	126.7
Lima beans (shelled)	80.6	107.8	275.2
Tomatoes	....	....	79.0

dioxide production of the component parts. It is also evident that the shelled beans had a much greater respiration rate than those in the comparison in Table I, although the rates for the pod samples were almost identical. The method of handling the shelled beans may account for the difference in respiratory behavior, since the lot represented in Table I were podded in a commercial viner and washed before being placed in the respiration chambers, while the sample in Table III was shelled by hand and placed in the chamber without delay.

The effect of preparation of the material upon rate of respiration was studied further with snap beans and sweet corn. A comparison of whole snap bean pods with pods with the tip ends removed and with pods cut into 1-inch lengths showed carbon dioxide production over a 7-day storage period at 38° F. for the respective lots to be 37.0, 41.7, and 41.2 mg. per kilogram-hour. It would seem that wounding entailed in the preparation had little effect on the rate of respiration. A comparison of the carbon dioxide output from kernels of sweet corn cut from the cob with a sharp knife with that of husked ears over an 8-day storage period at 32° F. showed that the separated kernels had a lower carbon dioxide production rate than did the husked ears. The average values were 35.9 and 40.7 mg. per kilogram-hour, respectively.

Table III. Effect of Husking Sweet Corn and Shelling Lima Beans on Carbon Dioxide Production[a]

Material Tested	Weight of Material, G.	Total CO_2 in 5 Days[a], G.	Respiratory Rate, Mg. CO_2/Kg./Hr.
Sweet corn in husk	1000	8.34	69.5
Husked ears from 1000 grams of corn	715	7.48	87.2
Husks from 1000 grams of corn	285	1.74	90.9
Husked ears plus removed husked (2 + 3)	1000	9.22	...
Lima beans, whole pods	1000	3.67	30.6
Seeds from 1000 grams of pods	318	3.49	98.4
Shells from 1000 grams of pods	682	4.32	52.6
Separated seeds plus shells (6 + 7)	1000	7.81	...

[a] Stored at 38° F.

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Serpentine-Fused Phosphate Shows High Liming Value; Mechanism of Chelate Action

SERPENTINE-FUSED PHOSPHATE

Equivalent Basicity, Solubility, and Liming Value

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Fertilizers prepared by fusing phosphate rock with serpentine and quenching the melt to a glass are manufactured in several countries, notably Japan and Taiwan. The equivalent basicity of such products and their solubility in ammonium citrate and citric acid solutions, as determined by standard laboratory procedures, are shown to be positively correlated with both the glass content and the fineness of the material. As indicated by laboratory tests with several types of soils, serpentine-fused phosphate has value as a soil-liming material.

THE BASIC NATURE of serpentine-fused phosphate is well known. However, of all the properties of such phosphate material so far reported (*6–10, 12, 13, 16*), the equivalent basicity appears to be the least understood.

Moulton states that 1 ton of olivine-fused phosphate containing 14% magnesium oxide is equivalent to 1200 pounds of limestone for soil sweetening (*14, 20*). It is believed that serpentine-fused phosphates which usually contain more than 14% magnesium oxide might have a higher equivalent basicity (*7*).

A further study of this property would result in a more thorough understanding of the soil-sweetening capability of serpentine-fused phosphate, a quantitative knowledge of which is essential to the use of this material in the formulation of non-acid-forming fertilizer mixtures.

Materials

Six samples of fused phosphate were used. Their sources and partial chemical analyses are given in Table I.

Sample TP was from a 2-ton lot of imported Thermo-Phos granular formerly manufactured by the Permanente Metals Corp., Permanente, Calif. This sample does not represent the average production, and the chemical properties