Growth and Respiration Patterns of Snap Bean Fruits
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Summary. The relationship of respiration and growth of seed, pericarp tissue and whole fruit of snap beans (Phaseolus vulgaris L.) was studied. The whole fruit exhibited an apparent climacteric type of respiration pattern. This pattern resulted from an increase in CO₂ production by the enlarging seed followed by a rapid decrease in CO₂ evolution by the pericarp tissue, and the pattern was not associated with any concomitant increase in ethylene production. Therefore, the apparent climacteric respiration pattern of a developing bean fruit is not comparable to the phenomenon that occurs in other ripening fruits.

The respiration pattern of many horticultural fruits exhibits a climacteric about the time the fruit undergoes ripening (1, 13, 15). In a recent study (16) detached bean fruits did not show this phenomenon; however, morphological changes that occur late in development of the fruit could mask the climacteric. In most fruits which exhibit the climacteric, the processes of maturation of the seeds and the pericarp tissue occur simultaneously. In beans the seeds do not begin to enlarge until the pericarp tissue is almost completely developed (3, 5). Previous workers (5, 7, 11) found the pattern of fruit growth to be sigmoid and the enlargement of seeds to be initiated about the time the fruit attained nearly maximum length. Growth pattern of the seed was reported to be a sigmoidal type (5, 9, 11); however, Carr and Skene (3) pointed out that the seed size increases in 2 stages and called it “diauxic” growth, a pattern commonly known as the double sigmoid curve. The object of this study was to relate the growth and respiration of developing seeds, pericarp tissue, and whole fruit of snap beans and to determine if a climacteric occurs in the respiration pattern.

Materials and Methods

Snap beans (Phaseolus vulgaris L. cv. Tendergreen) were grown in 20 liter cans in the greenhouse from September through June. The greenhouse temperature fluctuated with the outside temperature; the maximum temperature ranged from 27°C to 35°C and the minimum was controlled at 21.1°C.

For the growth study of the fruit, plantings were made in sequence in order to tag flowers daily for a period of 4 weeks. This was repeated 2 times. At the end of each 4-week period, all tagged fruits were harvested for measurements of length, weight, and seed weight. The number of seeds per fruit and visual description were also noted. Data of only those fruits containing 5 to 7 seeds were used, and the results presented are averages of the measurements based on days after anthesis. The number of fruits measured for each day varied from 4 to 12.

The respiration rate of the seeds, pericarp tissue, and whole fruit at 20°C was determined by measuring the amount of CO₂ evolved by the method of Claypool and Keefer (4) or with a Beckman infrared CO₂ analyzer. The respiration patterns of the developing tissues were determined indirectly by plotting the initial respiration rate of the tissues detached from the plant at various stages of growth and maturation. The respiration rates of the detached pericarp tissues and fruits dropped sharply for the first 10 to 12 hours of holding and then settled to a steady decrease. The initial rates of these segments were determined by extrapolating from the settled rates to “zero” hour. The respiration rates of the extracted seeds decreased rapidly and continually during the first 24 hours. The immature seeds were discolored by this time, hence the measurements were not continued and the rates after 12 hours of holding were used as the best index for the initial rates of the seeds.

The ethylene production of a few of the detached fruits was measured. The concentration of ethylene in the effluent air was measured by flame ionization gas chromatography (10).

Respiration measurements were also made with fruits attached to the plants, which were grown in a chamber controlled to 9 hours of dark at 20°C and 15 hours of light (3000 ft-c) at 25°C. The attached fruits were enclosed within small glass tubes through which humidified air was metered. A gas sample was taken daily on the eighth hour of the 9-hour
Results and Discussion

Growth Study. The growth pattern of bean fruit was sigmoid (fig 1), as observed by other workers (3, 5, 11). The length and weight began to increase about 4 days after anthesis. Maximum length was attained about the thirteenth day, which was due essentially to enlargement of the fleshy endocarp. Seed weight began to increase noticeably at about this time and seed size continued to increase within the cavity formed simultaneously by the collapse of the endocarp. Only the skeletal cell walls of the endocarp remained as the seed attained maximum size. Visual characteristics of the beans at different stages of maturity based on percentage of seed by weight are described in table I. The growth pattern of the seeds appeared to be a double sigmoid curve, due to the decreased growth rate from about the twentieth to the twenty-second day (fig 1). This was about the time the total fruit weight began to decline. Carr and Skene (3) have described the anatomical changes of the cotyledons, embryo axis, and seed associated with different stages of the double sigmoid curve.

The growth rate of the fruits varied with season and the extremes differed by as much as 35%; consequently the chronological age of days after anthesis could not be used as the basis for describing physiological changes as described by other workers (3, 5, 9, 11). The percentage of seed by weight, as used by several workers (2, 6, 8, 12, 14) was found to be the most desirable index for maturity in this study.

Respiration Study. The respiration rate of developing seeds, based on the initial rates of seeds from fruits detached at different stages of growth, decreased continuously from approximately 600 mg

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**Table I. Characteristics of the Fruits of Tendergreen Beans at Different Stages of Maturity Based on Percent Seed by Weight**

<table>
<thead>
<tr>
<th>Approximate % seed by wt</th>
<th>Description</th>
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<tbody>
<tr>
<td>Up to 8</td>
<td>Green fruit color, fleshy endocarp, seeds small and green, period of rapid fruit growth.</td>
</tr>
<tr>
<td>8-12</td>
<td>Pericarp showing slight bulges from growth of seed, near maximum length attained, ideal maturity for consumption.</td>
</tr>
<tr>
<td>12-16</td>
<td>Endocarp beginning to collapse, seeds beginning to grow rapidly, slightly overmature but edible.</td>
</tr>
<tr>
<td>16-22</td>
<td>Pericarp shows definite growth of seed, endocarp slightly pithy, beyond edible stage as snap bean.</td>
</tr>
<tr>
<td>22-28</td>
<td>Green fruit color fading, endocarp slightly to moderately pithy, green seed color becoming white.</td>
</tr>
<tr>
<td>28-34</td>
<td>Light green fruit color becoming white along suture, moderately pithy, seed color creamy white.</td>
</tr>
<tr>
<td>34-40</td>
<td>Endocarp moderately to completely pithy, veination on seed becoming prominent in coloration.</td>
</tr>
<tr>
<td>40-46</td>
<td>Whitish green fruit color, endocarp pithy, cream colored seeds with veins becoming blue.</td>
</tr>
<tr>
<td>46-50</td>
<td>Greenish white to yellowish white fruit color, endocarp almost a film, seeds light blue color.</td>
</tr>
<tr>
<td>50-54</td>
<td>Cream fruit color, thin pericarp, seeds blue.</td>
</tr>
</tbody>
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**Fig. 1.** Growth measurements of fruit weight, fruit length and total seed weight of Tendergreen beans from 4 to 28 days after anthesis. Total seed weight is also graphed as percentage of total fruit weight.
CO$_2$/kg-hr to 250 mg CO$_2$/kg-hr during the growth period studied (fig 2). The rate of decrease accelerated slightly at the stage of maturity of about 15% seed and thereafter was almost linear. Loewenberg (9) measured O$_2$ uptake of developing bean seeds, and the respiration pattern was similar to that noted in this study except that the slope of the decrease was greater at the beginning than it was during the remainder of the period. The absolute rates of O$_2$ uptake on the volume basis were approximately 15% greater than the rates for the CO$_2$ evolution with the younger seeds, but this difference decreased with time and the difference was almost nil with the more mature seeds. Since the bean seeds were undergoing changes to enter dormancy, not senescence, a climacteric was not expected to be exhibited in the respiration pattern.

The respiration rates of the young pericarp tissues fluctuated greatly, but in general the rates increased for a period and then decreased rapidly during the development of the tissue (fig 2). This resulted in an indistinct climacteric type of pattern. It is suspected that this pattern is not the true climacteric and that the small increase in rate resulted from an increased availability of respiratory substrate. Carbohydrate changes were not followed in this study, but Culpepper (5) found that reducing sugars increased at about this stage of growth.

The respiration rates of whole fruits, based on initial measurements, showed a climacteric type of pattern (fig 3). The rates of the younger fruits were related to chronological age since the changes in percentage of seed were very small. The respiration rates of young fruits decreased with growth, but began to increase when the fruit was near maximum length. The rate continued to increase with maturity up to about 22% seed, when the green fruit color began to fade, the endocarp was slightly to moderately pithy, and the seeds were becoming white in color. The rate increased again for a short period when the seed weight was approximately 30% and then declined as the fruit took on light color at about 50% seed by weight.

Respiration rates of developing fruits, as measured on the plant, also showed a climacteric type of pattern (fig 4). The respiration rate of very young fruits (not shown in fig 4) was approximately 700 mg CO$_2$/kg-hr, and the rate decreased rapidly with the growth of the fruit. As noted with respiration of detached fruit, the rate began to increase when the fruit was near maximum length and then began to decline at about the time the fruit had lost most of its green color. The peak width was narrower than that observed with measurements off the plant. This was due to a difference in the base used for maturity. Here the maturity was based on chronological time in terms of days before and after the fruit had attained maximum length.
The very close association of the changes in the respiration rate of the fruits to seed growth constitutes additional evidence that the increasing respiration rate of the fruit was due to the contribution of the enlarging seeds. The respiration rate began to increase when the seeds began to enlarge, and the rate attained a plateau about the time the seed growth entered the lag phase. The duration of the plateau and of the lag phase of growth were similar and the final increase in respiration rate occurred at about the beginning of the second phase of rapid growth, when the embryo axis grows most rapidly.

These analyses of the relationship between respiration and growth of seed, pericarp tissue and whole fruit indicate that the apparent climacteric in the respiration pattern of whole bean fruit should not be considered as a typical respiration climacteric, but should be understood in terms of differing contributions of volume of carbon dioxide by seed and pericarp tissues undergoing morphological and physiological changes.

The climacteric-type pattern observed with whole fruit does not appear to be the true climacteric evidenced by the indistinct climacteric type pattern exhibited by the pericarp tissue free of seeds, and by the absence of increased ethylene production during ripening which is observed in other fruits exhibiting the climacteric (1). The amount of ethylene produced by the beans at any stage of growth was approximately 4 µl/kg-hr.

The climacteric type of pattern appears to have resulted from the changes in the morphological structures during growth. Since the pericarp tissue is degenerating at the time the seeds are enlarging, the contribution by either tissue to the total respiratory activity depends on its size in proportion to that of the total fruit. Calculations showed that the quantity of CO₂ evolved by the pericarp tissue from a kg of fruit decreases with growth, whereas the quantity of CO₂ evolved by the seeds increased and leveled off with growth (fig 5). During the early stage of growth, the increase in the amount of CO₂ contributed by the seed was more significant than the decrease by the pericarp tissue; whereas during the latter stage, the decrease in the contribution by the pericarp tissue was more significant than the increase by the seed. The additive rate of the 2 resulted in a climacteric type of pattern. The additive rates are slightly higher than the rates of whole fruit, but the pattern of increasing and decreasing rate occurs at about the same maturity as in the whole fruit.

Fig. 4. Respiration rates of Tendergreen bean fruits developing and maturing on the plant. Ages of the fruits were on the basis of chronological time as days before and after the fruits attained maximum length.

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Fig. 5. Initial respiration rates of the pericarp tissues, seeds, whole fruits and the additive rates of pericarp tissues and seeds of Tendergreen beans, each from a kg of fruits at different stages of growth. Stage of growth was based on percentage seed by weight.

Literature Cited


