during storage to be recognized by the panelists. Panelists noted that bitterness of maturity-2 fruit was less than that of maturity-1 fruit, probably because of the degradation of phenols that occurs with maturation and ripening. On the other hand, although ripening continued during storage, the increased bitterness noted with CA storage probably was due to the production of stress metabolites. Mustiness probably was caused by the near static condition within the CA chambers. In other experiments (unpublished) we have noted that some tomatoes taste musty when stored in a static room. The increase of fermentedness implies that anaerobic respiration occurred during CA storage. The oxygen concentration was maintained at 1% within the chamber, but its concentration within the fruit could have dropped sufficiently for the anaerobic processes to be initiated.

The desirability of peaches stored in CA correlated closely with the fruitiness attribute. The stepwise regression analysis indicated that 95% of the variation of desirability in 'Redskin' was due to fruitiness and mustiness attributes, and that 84% of the variation of desirability in 'Rio Oso Gem' was due to fruitiness and fermentedness. The regression equations

'Redskin' desirability = 1.189 + 0.618 fruitiness – 0.829 mustiness

'Rio Oso Gem' desirability = 0.600 + 0.713 fruitiness – 0.470 fermentedness

indicate that mustiness and fermentedness had a definite effect on desirability of the peaches. Scores of both attributes were very low, but they were equally as important as the fruitiness scores for determining the desirability score.

Some of the variations in sensory attributes can be accounted for by the composition, including headspace volatiles. The pH accounted for a large part of the variation of fruitiness, mustiness and desirability, whereas volatiles was responsible for only a small part of the variation. Peak 1 accounted for only 4% of the variation of fruitiness and mustiness, and 8% of desirability, and peak 8 accounted for only 2% of the variation of desirability. Generally, the amount of accountable variation was larger when the ln of peak area was used for analysis. This probably was due to the logarithmic relationship between sensory response and substance concentration.

Relationships between specific volatile peaks and sensory attributes were different for the two cultivars. In headspace analysis, only low boiling components were observed and the high boiling components which may have an effect on the sensory attributes were not observed. Nevertheless, chromatograms of headspace analysis provide useful patterns that can be related to the sensory responses stimulated by the total volatile mixture.

In conclusion, peaches in controlled atmosphere with intermittent warming were maintained 2 to 3 times longer than those reported for air storage (1); however, intensities of a few attributes, which correlated negatively with desirability, became apparent with extended CA storage. The chemical identification of these attributes is not known and needs further investigation.

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A Nondestructive Method for Measuring Ripeness and Detecting Core Breakdown in 'Bartlett' Pears[1]

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Abstract. **Difference in optical density (ΔOD) of intact 'Bartlett' pears (*Pyrus communis* L.) between wavelengths 690 and 740 nm was measured at harvest and during ripening with a single-beam multiwavelength spectrophotometer. The ΔOD indicated the status of ripeness and detected core breakdown of 'Bartlett' pears nondestructively. The ΔOD decreased consistently with ripening and was associated with softening, climacteric rise in respiration, and ethylene production. The ΔOD increased in pears with core breakdown even before external symptoms were visible.**

The quality of a pear is often misjudged when it is consumed or evaluated at the wrong stage of ripeness. A pear does not attain its highest dessert quality until it has been properly ripened to the right stage. However, ripeness is difficult to evaluate without cutting into the fruit. The need for an accurate, nondestructive method for measuring ripeness is especially notable in 'Bartlett' pears, which ripen quickly, have a short shelf life, and are susceptible to core breakdown, particularly in pears picked late in the harvest season (2).

Variation in ripeness of 'Bartlett' pears is often encountered at the time of processing (5). This variation can be attributed to variability in maturity at harvest or to improper handling after harvest. Problems arise when pears do not ripen uniformly and cannot be segregated nondestructively according to their degree of ripeness.

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Worthington et al. (11) reported that pear maturity and ripeness might be estimated nondestructively. They demonstrated that certain differences in optical density (ΔOD) of transmitted light measured at 2 different wavelengths were associated with ripeness of pears at harvest, during storage, and after storage (12). However, data on respiration rates and ethylene production of the pears during ripening were not presented.

In this study, we evaluated the effectiveness of this nondestructive technique for assessing ripeness of 'Bartlett' pears and examined the relation of ΔOD to physiological changes and the development of core breakdown during ripening.

Materials and Methods

Samples. 'Bartlett' pears at optimum maturity based on a firmness test of 7.7 kg were picked from mature trees at the Beltsville Agricultural Research Center. Fruits chosen for the experiment were free from blemishes and were 6.5 to 7.0 cm in diameter.

Storage and ripening. Fruit samples were stored at 0°C in bulk in wooden boxes with multiperforated polyethylene liners for 2.5 months in the 1977 season and for 3 months in the 1978 season. The lengths of storage were sufficiently long to fulfill the chilling requirement for adequate ripening (6, 13) and to induce core breakdown in some samples. After storage, pears were ripened in a room kept at 20°.

Measurement of firmness, respiration, and ethylene production. Firmness was measured on the pared surfaces of the fruits using a Magness-Taylor pressure tester fitted with a 8-mm plunger tip. Twenty fruit were used daily during ripening for the measurement of firmness.

Twenty pears were each placed in a 1 liter jar for determination of respiration and ethylene production. The jars were sealed for 1 hr each day at 20°C and the accumulated CO_2 and C_2H_4 were analyzed with a Fisher model 29 gas partitioner and a gas chromatograph, respectively.

Light transmittance measurement. Differences in optical density between wavelengths of 690 and 740 nm of each intact pear were measured with a single-beam multiwavelength spectrophotometer. All fruits in the experiment were measured once a day. The construction and methodology of the spectrophotometer were described previously (9, 11). Precautions were taken to enhance the uniformity of the measuring system: only fruit with similar diameter were used to reduce variation because of size and all fruit were placed in the sample holder in the same orientation to minimize variation due to difference in position.

Results

Changes of ΔOD and firmness during ripening. Values of ΔOD ranged from .600 to .900 at harvest for 'Bartlett' pears (data not shown). They decreased to around .300 after 2.5 to 3 months' storage at 0°C. Fig. 1 shows a steady decline of ΔOD during ripening at 20° after storage. The decline is closely related to the decrease in firmness. While firmness decreased from 6.4 to 1.2 kg in 5 days, the ΔOD decreased from .300 to –.200 in the same period. Fruits were ready to eat on the fourth day when firmness was 1.6 kg and the value of ΔOD was –.150.

Changes of ΔOD, ethylene production and respiration during ripening. Both ethylene production and respiration showed a typical climacteric rise during ripening at 20°C. Peaks for ethylene and carbon dioxide production were on the 3rd day corresponding to the ΔOD value of .014 When ΔOD fell below this value, the ripening process progressed into the post-climacteric phase. Thus, the values of ΔOD which are measured nondestructively, can be used to estimate the time of the climacteric maximum and can be used as an index for the ripening status of pears.

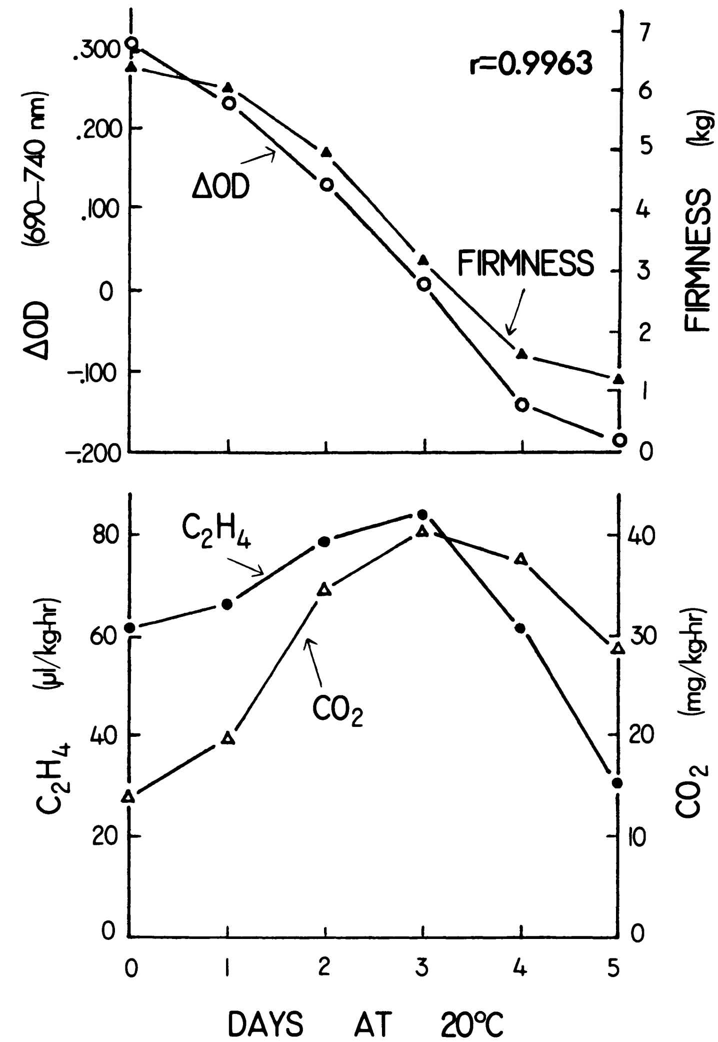

Fig. 1. Changes of ΔOD, firmness, ethylene, and carbon dioxide production during ripening of 'Bartlett' pears at 20°C. Values are means of 20 measurements.

Detection of core breakdown by ΔOD. Four representative samples (Table 1) illustrate that core breakdown did affect ΔOD. The pear with no symptoms of breakdown (sample A), when cut on day 5, had ΔOD values that decreased continuously. Pears with slight and moderate breakdown (samples B and C) had ΔOD values that decreased at first but then increased. The pear with severe breakdown (sample D) had ΔOD values that increased continuously. In all fruit, ΔOD values began to increase before symptoms of core breakdown were visible externally.

Table 1. Core breakdown and ΔOD at 690-740 nm in 'Bartlett' pears ripened at 20°C for 0 to 5 days.

	ΔOD						
	Days at 20°C						Core
Sample	0	1	2	3	4	5	breakdown
A	.302	.234	.137	.014	–.146	–.207	None
B	.276	.208	.132	.018	.075	.112	Slight
C	.289	.201	.118	.155	.236	.371[z]	Moderate
D	.265	.348	.402[z]	.582[z]	.651[z]	.778[z]	Severe

[z]Symptoms of core breakdown visible externally.

Discussion

As pear fruit ripen, ΔOD values decrease. Worthington et al. (11) postulated that ΔOD measurements reflect a change in the state of water in the tissues. The change in water status from bound to free during maturation and ripening could alter the light scattering properties of tissues and thus change their optical densities.

Differences in the optical density measurements between other wavelengths have also been tested for assessing the maturity and ripening of pears (11). However, the most recent experiments showed that using the ΔOD at 690-740 nm provided the best correlation with maturity and ripening (12). Therefore, we used this pair of wavelengths throughout our study. Measurements of ΔOD with various pairs of wavelengths have been used to detect water core in apples (1), to evaluate quality in citrus fruits (3), to detect chilling and mechanical injury in tomatoes (10), and to determine firmness in peaches (8).

Monitoring of the ΔOD of pears during storage detected the development of core breakdown, which shortens the post-harvest life of 'Bartlett' pears. Pears grown in cool regions and fruits picked past their optimum maturity are more likely to develop this disorder (2, 4, 7). The symptoms of core breakdown are usually not visible externally until it has progressed to the moderate or severe stage. Nondestructive means of detecting the occurrence of this disorder at early stages of ripening would enhance the efficiency of the postharvest operation, reduce the unnecessary wastage of energy and labor, and increase the product quality for both processing and fresh markets.

To accurately detect the initiation of core breakdown, ΔOD of a pear has to be continuously measured throughout the ripening process. The trend of decreasing or increasing of ΔOD values can only be obtained when changes are followed continuously. This would also avoid the potential confusion in interpreting the data when attempting to correlate ΔOD and ripeness.

Measurement of ΔOD provides a definable, repeatable index of ripeness that can be obtained nondestructively. If the end point of ΔOD for the eating-ripe stage can be established for various pear varieties, it might be possible to estimate the numbers of days required to develop the full flavor for the particular lot of pears. Information of this nature would be especially valuable for some of the commercially important, slow ripening cultivars such as 'Anjou,' 'Bosc,' and 'Comice' pears. Preconditioning techniques for fresh market pears that initiate the ripening process before shipment may be refined and improved if information on numbers of days to reach the eating-ripe stage at different situations is available.

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