Morphological and Physiological Changes during Fruit Growth and Maturation of Seven Melon Cultivars

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Abstract. External color, length, diameter, fresh weight, CO_2 production, internal C_2H_4 concentration, flesh firmness, soluble solids concentration (SSC), flesh color, and seed cavity diameter were measured during fruit growth and maturation of seven melon cultivars (*Cucumis melo* L., Inodorus Group, Naud. cv. 'Amarelo', 'Golden Beauty Casaba', 'Honey Dew', 'Honey Loupe', 'Juan Canary', 'Paceco', and 'Santa Claus Casaba') of known age. There was no increase in CO_2 production either during ripening (e.g., loss of firmness and increased SSC) or with increasing C_2H_4 levels in fruit from any of the seven cultivars. There was a significant decline in respiration only at the second sampling date, which ranged from 14 to 18 days after anthesis. Respiration measured 1 week later was substantially higher and was followed by a general decline. This post 14- to 18-day rise in respiration was not a climacteric since it occurred well in advance of other ripening characteristics, e.g., loss of firmness, increase in SSC, or rise in internal C_2H_4 . The increase in internal C_2H_4 coincided with or followed attainment of full fruit size, while flesh softening and the rapid rise in SSC preceded the rise in internal C_2H_4 concentration. Respiration declined from 67 to 18 ml CO_2 /kg per hour by day 43 in all cultivars, except 'Honey Dew' and 'Honey Loupe'. Respiration in 'Honey Loupe' remained above 23 ml CO_2 /kg per hour and showed a rise to 32 ml/kg per hour on day 53. Respiration in 'Honey Dew' did not fall below 18 ml CO_2 /kg per hour until day 53. As with internal C_2H_4 levels, there was no correlation between changes in and any marked change in the other signs of ripening that were measured.

Morphological and physiological changes during fruit growth, maturation, and ripening of many melon cultivars have not been studied extensively, even in countries where the fruit are grown commercially and are very popular. Many diverse types of melons are marketed; they differ in shape, external and internal color, surface netting, sweetness, flavor, and storability. While muskmelons have long been popular in the United States, casabas are only now becoming as popular with American consumers as they are with consumers in other countries.

The best flavor for melons depends on sweetness and on various volatile compounds that are not yet fully identified (Yamaguchi et al., 1977). Sweetness is only partially correlated with SSC, and a high SSC alone does not adequately define good melon quality (Aulenbach and Worthington, 1974; Yamaguchi et al., 1977); but while all melons with high SSC are not necessarily of good quality, the absence of high SSC makes good quality very unlikely (Bianco and Pratt, 1977). Changes in other characteristics during growth and ripening are also important in determining quality. Some of these include changes in external and flesh colors, weight, length, diameter, flesh firmness, and seed cavity diameter. Measurements of the respiration rate (CO_2 production) and internal C_2H_4 concentration are useful indicators of changes taking place during ripening, e.g., the climacteric.

Ethylene and CO_2 production during ripening are among the few physiological changes that have received extensive study in melons (Bianco and Pratt, 1977; Pratt, 1971; Pratt et al., 1977). Many cultivars of harvested summer melons (*C. melo*, Reticulatus group) exhibit a climacteric increase in C_2H_4 and CO_2 production during ripening, while fruit of other cultivars, termed winter melons (*C. melo*, Inodorus group), have a negligible or

much less pronounced increase in C_2H_4 and CO_2 production (Kitamura et al., 1975; Pratt, 1971). The climacteric ripening of 'Honey Dew' melons (Inodorus group) has been thoroughly studied, with seven maturity classes defined: 1) immature, 2) mature but unripe, 3) full mature, 4) ripening initiated, 5) ripe, 6) overripe, and 7) senescent (Pratt et al., 1977).

There is a great deal of variability in growth and quality within muskmelon cultivars (Bianco, 1966; Reid et al., 1970; Yamaguchi et al., 1977). Much of this variability has been attributed to differences in growing conditions (Bianco and Patrino, 1968; Davis et al., 1967; Dellacecca, 1968). In the present study, melon cultivars that are popular in Italy and other cultivars that are popular in the United States were grown at Davis, Calif., to study their growth and maturation under identical growing conditions. We present a detailed examination of morphological and physiological changes during the growth, maturation, and ripening of seven melon cultivars. The relationship among CO_2 and C_2H_4 production and other signs of ripening is examined.

Materials and Methods

Plant material. 'Amarelo', 'Golden Beauty Casaba', 'Honey Dew', 'Honey Loupe', 'Juan Canary', 'Paceco', and 'Santa Claus Casaba' melons were planted on several dates around the middle of May at the Univ. of California Vegetable Crop farm, Davis. Normal cultural practices for the area were followed for irrigation, fertilizer, and pesticide application. Distillate flowers were tagged at anthesis (McGlasson and Pratt, 1963), and all data refer to fruit age as days after anthesis. Five fruit were gently hand-harvested at weekly intervals about 7:30 AM and quickly transported to the laboratory where they were weighed and examined for external color and shape. External and flesh colors of individual fruit were determined by comparison with tables in the Munsell Book of Color (Munsell, 1929). Calipers

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Abbreviations: L : D, length : diameter, SSC, soluble solids concentration.

were used to measure the diameter and length of each fruit. Reported data are from measurements of five fruit from each of two harvests.

Carbon dioxide and C_2H_4 production. Production of CO_2 was measured by analyzing 1-ml gas samples taken from the headspace of glass containers in which the fruit had been enclosed at 20°C for 1 to 4 h (Horiba Model PIR-2000 infrared gas analyzer; Horiba Instruments, Irvine, Calif.) (Saltveit, 1982). Container volume and enclosure time were varied so that the CO_2 concentrations did not exceed 0.2%. For most of the time during the growth of the fruits, the rate of CO_2 production was so much greater than the rate of C_2H_4 production that, given the 0.2% limit for CO_2 , the concentration of C_2H_4 that accumulated during the enclosure period was near the detection limit of the gas chromatography. The internal C_2H_4 concentration was determined because 1) it was higher and, therefore, more accurately measured, and 2) it better reflects the tissue C_2H_4 concentration and, therefore, its potential hormonal activity than would rates of evolution from the fruit. After equilibration in air at 20°C for 3 h, internal gases were sampled by inserting a syringe needle into the hollow central cavity and withdrawing a 7-ml gas sample with a 10-ml syringe (Saltveit, 1982). Ethylene was measured using a Carle analytical gas chromatography (model 211) with a flame ionization detector (Hach Co., Loveland, Col.). Internal C_2H_4 concentrations are presented on a log scale since the biological activity of C_2H_4 is log-linear; i.e., a log increase in concentration produces a linear response in most plant tissues studied (Goeschl and Kays, 1975).

Internal characteristics. Each fruit was cut in half along the equatorial plane, and the internal color, flesh firmness, percent SSC, and thickness of the mesocarp were measured. Seed cavity tissue consisted of the gelatinous, seed-containing tissue (e.g., the seeds and associated placental material), while the mesocarp consisted of the edible tissue between the peel (skin) and the seed cavity tissue. The diameter of the seed cavity was calculated by twice subtracting the mesocarp thickness from the fruit diameter.

Flesh firmness was measured with a Hunter Spring Pressure Tester (model L-10M; McCormick's Fruit Tech. Co., Yakima, Wash.) using a 2.4-cm-long x 8-mm-diameter plunger. The rind was removed from two 6 x 5-cm sections of tissue cut from opposite equatorial zones of the halved fruit, and four to six firmness readings per section were recorded. The SSC was determined using a hand-held Bausche and Lomb Abbe-3L refractometer (VWR Scientific, San Francisco). Liquid was squeezed from two $\approx 2 \times 2$ -cm pieces of mesocarp tissue cut from opposite equatorial zones of the halved fruit and carefully mixed before evaluation.

Results and Discussion

Size and shape. Full-sized fruit of 'Paceco', 'Amarelo', 'Juan Canary', and 'Honey Dew' weighed ≈ 2.3 kg (Figs. 1 and 2). The lightest mature fruit was 'Honey Loupe' at 1.4 kg, while the two casabas were the heaviest at 3.0 kg for 'Golden Beauty Casaba' and 3.3 kg for 'Santa Claus Casaba'. Mature 'Paceco' fruit was longest and had the smallest diameter to produce the largest length : diameter (L : D) ratio, i.e., 2.04—an elongated ovoid. 'Santa Claus Casaba' fruit were only slightly shorter than 'Paceco' fruit, but their much larger diameter reduced the L : D ratio to 1.65—an ovoid. 'Juan Canary' and 'Amarelo' fruit were also ovoid, with intermediate lengths and diameters that produced L : D ratios of 1.47 and 1.28, respectively. The most spherical fruit were 'Honey Loupe', 'Honey Dew', and 'Golden

Fig. 1. Changes in diameter, fresh weight, length, and seed cavity diameter during growth and maturation of 'Amarelo', 'Honey Loupe', 'Paceco', and 'Juan Canary' melons. Data are the average of measurements of five fruit from each of two harvests. Vertical bars represent 5% LSD for each measurement.

Beauty Casaba', with L : D ratios of 1.16, 1.11, and 1.01, respectively. Mature 'Honey Dew' and 'Golden Beauty Casaba' fruit had seed cavities that accounted for $\approx 50\%$ of their external diameters. This proportion differed substantially from the average 3770 found in all other cultivars, except for 'Amarelo', which had an intermediate value of 45%.

Color. The external color of full-sized fruit ranged from yellow for 'Juan Canary', 'Amarelo', and 'Golden Beauty Casaba', to yellowish-green for 'Honey Loupe', 'Santa Claus Casaba', and 'Paceco', and to greenish-yellow for 'Honey Dew'. The internal flesh color ranged from nearly white in 'Golden Beauty Casaba' to orange in 'Honey Loupe', 'Amarelo', and 'Santa Claus Casaba'. 'Honey Dew' had a slightly more greenish flesh than 'Juan Canary' and 'Paceco', both of which were greenish-yellow.

Changes in firmness. All cultivars softened to below 50 N within 60 days of anthesis (Fig. 3). 'Golden Beauty Casaba' and 'Juan Canary' were the firmest fruit early in development, ≈ 275 N. The other cultivars had firmness values of ≈ 185 N before starting to soften. Although there was a slight decrease in firmness at the second sampling, 'Amarelo' and 'Santa Claus Casaba' did not start to show continual softening until after day 28, while the other cultivars had all started to soften by day 22. The cultivar that initiated softening first was 'Golden Beauty Casaba', which started on day 14.

There were two distinct groups of melons evident by the time

Fig. 2. Changes in diameter, fresh weight, length, and seed cavity diameter during growth and maturation of 'Golden Beauty Casaba', 'Honey Dew', and 'Santa Claus Casaba' melons. Data are the average of measurements of five fruit from each of two harvests. Vertical bars represent 5% MD for each measurement.

Fig. 3. Changes in flesh firmness during growth and maturation of 'Amarelo', 'Golden Beauty Casaba', 'Honey Dew', 'Honey Loupe', 'Juan Canary', 'Pateco', and 'Santa Claus Casaba' melons. Data are the average of measurements of five fruit from each of two harvests. Vertical bars represent the overall 5% LSD.

they reached 155 N. 'Honey Dew', 'Honey Loupe', and 'Pateco' reached 155 N by day 24, while the rest of the cultivars did not reach this degree of softness until day 30. This grouping

did not persist during the subsequent softening to 55 N. All but one cultivar, 'Santa Claus Casaba', reached this level of softness by day 44 (range 43-47 days). 'Santa Claus Casaba' did not soften to 55 N until day 52.

Once softening had started, 'Amarelo' and 'Juan Canary' softened the fastest, going from 155 to 60 N in only 12 days. 'Golden Beauty Casaba' required 16 days, while the other four cultivars required an average of 22 days (range 19-24 days) to soften from 155 to 60 N.

Changes in SSC. All cultivars showed an increase in their rate of SSC accumulation after they reached a level of $\approx 6\%$ (Fig. 4). The increase was not as dramatic in 'Golden Beauty Casaba' and 'Santa Claus Casaba'. On day 28, the SSC of all cultivars was within 12% of the mean of 5.2% (range from 4.6% to 5.8%). Two weeks later, the spread had increased to 27% (range from 8.3% to 13.6%, mean of 10.7%). The range of SSC was evenly distributed among the cultivars, with 'Amarelo' having the highest and 'Golden Beauty Casaba' the lowest.

The time required for SSC to increase from 6% to 10% can be used to compare its rate of accumulation among cultivars. 'Amarelo' required only 6 days, while 'Honey Dew', 'Honey Loupe', and 'Juan Canary' required 8 days. 'Pateco' and 'Santa Claus Casaba' required 12 and 13 days, respectively, while 'Golden Beauty Casaba' required the longest, 17 days. 'Golden Beauty Casaba' also required the longest time to reach 6% (36 days) and the longest time to reach 10% (53 days).

There was poor correlation among the cultivars with regard to softening and increasing SSC. For example, while 'Pateco' and 'Santa Claus Casaba' were two of the three slowest softening cultivars, taking ≈ 22 days to soften from 155 to 60 N, and also two of the three slowest in increasing SSC, 'Golden Beauty Casaba', which was the slowest in accumulating SSC, was one of the fastest softening cultivars.

Changes in internal C_2H_4 concentration. The internal concentration of C_2H_4 remained below 10 ppb in all cultivars for most of their growth (Fig. 5). Upon reaching 10 ppb, the C_2H_4 concentration in all cultivars except 'Honey Loupe' increased in a typical climacteric fashion. 'Honey Loupe' was the first cultivar to show an increase in C_2H_4 concentration, surpassing 10 ppb on day 21. The concentration quickly increased to ≈ 35 ppb and then remained at that level for more than 2 weeks.

Fig. 4. Changes in SSC during growth and maturation of 'Amarelo', 'Golden Beauty Casaba', 'Honey Dew', 'Honey Loupe', 'Juan Canary', 'Pateco', and 'Santa Claus Casaba' melons. Data are the average of measurements of five fruit from each of two harvests. Vertical bar represents the overall 5% LSD.

Fig. 5. Changes in the internal C_2H_4 concentration during growth and maturation of 'Amarelo', 'Golden Beauty Casaba', 'Honey Dew', 'Honey Loupe', 'Juan Canary', 'Paceco', and 'Santa Claus Casaba' melons. Data are the average of measurements of five fruit from each of two harvests. Vertical bar represents the overall 5% LSD.

Ethylene concentration then rapidly increased, reaching the highest level of any cultivar, >13 ppm, in another 2 weeks (data not shown). This odd behavior in 'Honey Loupe' was not reflected in any noticeable way in firmness or SSC changes. 'Golden Beauty Casaba' and 'Santa Claus Casaba' required the longest time to reach 10 ppb, both surpassing this level on day 51. The other four cultivars surpassed 10 ppb at about day 39 (range 37-40 days).

The rate at which the internal concentration of C_2H_4 increased varied greatly among the cultivars. One week after surpassing 10 ppb, the C_2H_4 concentration had increased from 1.4-fold in 'Paceco' to 20-fold in 'Juan Canary'. The average internal C_2H_4 concentration of 15.7 ppb in 'Paceco' was the lowest recorded from full-sized melons of any of the seven cultivars. 'Golden Beauty Casaba' and 'Amarelo' also showed slow 2.9- and 4.7-fold increases, respectively. A more rapid increase was seen in 'Santa Claus Casaba' and 'Honey Dew', with 7- and 8-fold increases, respectively.

In an extensive study of the development and ripening of 'Honey Dew' melons, Pratt et al. (1977) measured internal C_2H_4 concentrations in 20- to 40-day-old fruit that were sampled while attached to the plant in the field and at 24 and 48 h after they were harvested. Internal C_2H_4 levels remained between 3 and 7 ppb for samples taken from attached or harvested fruit over the 20 to 40 days of fruit development. These levels of C_2H_4 were very similar to levels we measured within 5 h of harvest for comparably aged fruit (Fig. 5). The similarity in these measurements indicate that our harvesting and handling procedures did not markedly increase internal C_2H_4 levels from that of attached fruit.

Changes in CO_2 production. Rates of CO_2 production from 'Honey Dew' fruit harvested at 20 to 50 days after anthesis (Fig. 6) and measured within 5 h of harvest were consistently 2.6 to 1.3 times higher, respectively, than those of fruit that were at a similar age when measured by Pratt et al. (1977) 24 h after harvest. The discrepancy between Pratt's measurements and ours declined with advancing fruit age.

The rate of CO_2 production declined rapidly in freshly harvested melons. Values reported by Pratt et al. (1977) were measured 24 and 48 h after harvest and showed a continuous and

Fig. 6. Changes in the rate of CO_2 production during growth and maturation of 'Amarelo', 'Golden Beauty Casaba', 'Honey Dew', 'Honey Loupe', 'Juan Canary', 'Paceco', and 'Santa Claus Casaba' melons. Data are the average of measurements of five fruit from each of two harvests. Vertical bar represents the overall 5% LSD.

rapid decline in subsequent measurements until the climacteric was initiated in 35-day-old or older fruit. 'Ogen' (*C. melo* L.) melons that were harvested at 6 to 50 days after anthesis also had consistently lower rates of CO_2 production than fruit on the vine (Zisman and Temkin-Gorodeiski, 1975). Our measurements were taken within 5 h of harvest (Fig. 6). We believe that the higher respiration rates we measured are not the result of harvesting and handling stress (as confirmed by the lack of stress-induced C_2H_4 production), but are closer to the naturally higher respiratory rate of attached fruit. Also, extrapolation of the first two measured respiration rates reported by Pratt et al. (1977) back to zero time gives respiration values much closer to those reported here. Production of CO_2 was, therefore, measured within a few hours of harvest because we feel that such measurements more closely approximate the actual respiratory rate of attached fruit. In most studies, however, CO_2 production has been measured from stored fruit many days after harvest (Pratt, 1971; Pratt et al., 1977). Because of this difference in timing of respiration measurements, our results may not be comparable with other reported measurements of CO_2 production.

When harvested at full size and held in storage, 'Honey Dew' melons go through a characteristic CO_2 and C_2H_4 climacteric (Pratt et al., 1977). Pratt et al. (1977) found that the maximum rate of CO_2 production during the respiratory climacteric occurred at about day 55 for fruit harvested between 39 and 51 days. In contrast, we observed that CO_2 production from our freshly harvested fruit, except for 'Honey Loupe', continued a uniform decline from day 20 to 55. While we detected a very prominent rise in the internal C_2H_4 concentration after day 35, we did not detect an increase in CO_2 production during ripening. A similar increase in the internal C_2H_4 concentration without a concomitant rise in CO_2 production was noted by Saltveit (1977) in attached ripening bell peppers. In contrast to melons, the rise in internal C_2H_4 in peppers coincided with ripening of attached fruit. The climacteric rise in CO_2 production was observed by Pratt et al. (1977) only when mature fruit were allowed to ripen in storage. Fruit of 'Honey Dew' harvested at the same age as mature fruit that showed a climacteric rise in CO_2 production did not show a similar climacteric rate of CO_2 production in their immediate measurement. This intriguing observation was not mentioned in Pratt's paper.

The absence from our data of the well-documented respiratory climacteric in 'Honey Dew' melons could imply that the similar absence of a respiratory climacteric in all seven cultivars was the result of using freshly harvested rather than stored fruit. The presence of a respiratory climacteric in ripening stored fruit, but not in freshly harvested fruit that had been ripened on the vine, suggests that the CO₂ climacteric may be inhibited in fruit attached to the plant. A ripening inhibitor translocated from the plant into developing fruit has been proposed for apples (Sfakiotakis and Dilley, 1973). Another possibility is that the preclimacteric minimum that precedes the climacteric rise in harvested fruit and accentuates the magnitude of the climacteric rise is in reality an artifact of using detached fruit.

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