Relationships Among Day of Year of Drop, Seed Number, and Weight of Mature Apple Fruit

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Abstract. Preharvest fruit drop of apple [*Malus ×domestica* (L.) Borkh.] can cause significant crop losses, but factors controlling date of individual fruit drop are unknown. In three types of experiments, we investigated the relationships among seed number/fruit, fruit weight, and day of year of drop. By shading in mid-May and stigma excision before bloom, we induced variability in seed number. Dropped fruit were weighed, and their seeds were counted daily from late August until all fruit had dropped. Nontreated trees were studied similarly. Regression analyses were used to assess relationships among day of drop, fruit weight, and seed number/fruit. Substantial variation in day of drop of individual fruit was not explained by seed number of the fruit in these experiments with ‘Smoothie Golden Delicious’, ‘Redchief Delicious’, and ‘Commander York’.

Preharvest fruit drop often causes severe crop losses of several important apple cultivars of the northeast and mid-Atlantic states. The problem has been controlled partially using plant growth regulators (PGRs). Factors affecting response to PGRs and seasonal variation are poorly understood. Even less is known about factors determining which of the fruit on a tree abscise first. Although Walsh (1977) concluded that the fruit of ‘Lodi’ and ‘McIntosh’ drop shortly after the onset of the climacteric, the time from climacteric rise to drop varied from 3–25 d. In the postbloom period, fruit set and retention is related to hormone production by the seeds (Dennis, 1967; Luckwill, 1953). Seed number/fruit has been implicated in the developmental regulation of apple fruit growth and final size (Murneek and Schowengerdt, 1935; Williams, 1977). Higher seed numbers also were correlated with later drop in mature ‘McIntosh’ apples (Southwick, 1938a, b), but seed number explained only a small amount of the variation in time of drop. Whether or not seed number affects the time of preharvest drop for other cultivars is unknown.

If seed number does affect the time of drop, preharvest drop losses could be predicted by sampling fruit to determine seed number, and thinning practices that affect seed number could be modified to reduce losses. Similarly, any effect of seed number on fruit weight may be important to growers choosing among avail-

able thinning options. A relationship between fruit weight and date of drop may be useful for evaluating the cost of preharvest losses and deciding upon appropriate control measures.

The objectives of these experiments were to investigate the relationships among seed number, day of year of drop, and weight of individual apple fruit of three commercially important cultivars having varying tendencies for preharvest drop problems.

Materials and Methods

Stigma-excision experiment. Trees used in this experiment were 6-year-old ‘Smoothie Golden Delicious’/M.26 (GD), ‘Redchief Delicious’ Mercier strain/M.26 (D), and ‘Commander York’/Mark (Y) maintained using conventional commercial practices. All experiments were conducted at the Virginia Tech. College of Agriculture and Life Sciences Kentland farm, near Blacksburg, Va. Full bloom occurred on 16, 17, and 19 Apr. for the D, GD, and Y trees, respectively (days 106, 107, and 109 of the year, respectively). Lateral flowers were removed from each spur and petals were removed from unopened (“popcorn” stage) “king” flowers, which were tagged to receive one of six treatments in a completely randomized design. Only flowers with five stigmata were used, and each flower was considered an experimental unit. The six treatments were pinching off 0, 1, 2, 3, 4, or 5 styles below the stigma from each of 25 flowers/cultivar. The remaining stigmata were hand-pollinated on the second day following treatment. Flowers of D were pollinated with GD pollen and Y and GD flowers were pollinated with D pollen. Treatments were applied on 13, 17, and 19 Apr. 1995 to D, GD, and Y, respectively. Beginning 26 Aug., fruit were collected daily as they fell from the

tree until all fruit had fallen. Fruit collected on a given day were placed in a paper bag and stored in conventional cold storage at 2 °C until evaluation. The weight of each fruit was recorded. Fruit were cut open and the number of plump seeds and aborted seeds were counted. Fruit without an attached pedicel were considered to have been pushed off by other fruits and were omitted from the analysis.

Data from all treatments were pooled, and regression analyses were conducted using the REG procedure of the SAS system (SAS Institute, Cary, N.C.). The regressors (plump seed number, aborted seed number, and individual fruit weight) were evaluated for their effects on time of drop. Plump seed number and aborted seed number were evaluated for their effects on individual fruit weight.

Shading experiment. The experimental units were 6-year-old ‘Redchief Delicious’ Campbell strain/M.26 trees maintained using conventional commercial practices. Trees were blocked on uniformity of bloom, and one tree in each of two blocks was randomly assigned to receive one of four treatments. Trees were completely covered with 92% black plastic shade fabric (saran) for 0, 1, 2, or 3 d. Shade was imposed beginning 12 May when mean fruit diameter was ≈13 mm. The experimental design was a randomized complete-block with two blocks. Data were collected, pooled for each treatment and regression analyses were conducted as in the stigma excision experiment. Simple linear regression was used to define the relationship between number of fruit/tree and average time of drop.

Natural-drop experiment. Trees used in this experiment were 6-year-old ‘Smoothie Golden Delicious’/M.26, ‘Redchief Delicious’ Mercier strain/M.26, and ‘Commander York’/Mark maintained using conventional commercial practices. Two trees each of GD and D and three of Y were used. Fruit under each tree were collected daily until all fruit had abscised. Data were collected as in the stigma excision experiment and analyzed separately for each cultivar. Regression analyses were conducted as in the stigma-excision experiment.

Results

Stigma-excision experiment. No multiple regression models explained significantly more variation than simple linear relationships among the variables: plump seed number, aborted seed number, fruit weight, and day of year of drop. For D (Fig. 1), but not GD and Y (data not shown), fruit weight increased linearly with increasing numbers of plump seeds. Fruit weight of Y increased linearly with time of drop (Fig. 2), but no similar trends existed for D or GD. There were no significant relationships between aborted or plump seed numbers and day of drop for any of the cultivars (data not shown).

Shade experiment. Shading for 3 d caused all the fruit to abscise (data not presented). When the 0, 1, and 2 d of shade treatments were pooled, no significant relationships between date of drop, plump seed number, aborted seed number, and fruit weight were detected (data

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Fig. 1. The relationship between fruit weight and number of plump seeds/fruit for 'Delicious'. Regression line: $Y = 156.39 + 6.908X$; $r^2 = 0.303$, $P \leq 0.0001$, $n = 51$ (Stigma-excision expt.).

Fig. 2. The relationship between fruit weight and day of year of drop for 'York'. Regression line: $Y = -255.50 + 1.289X$; $r^2 = 0.328$, $P \leq 0.0001$, $n = 84$ (Stigma-excision expt.).

Fig. 3. Effect of number of fruit/tree on average day of year of drop of 'Delicious' fruit. The relationship is described by $Y = 226.09 + 0.0201X$; $r^2 = 0.819$, $P \leq 0.0001$, $n = 6$ (Shade expt.).

not shown). Day of year of drop increased linearly with crop load (Fig. 3); however, the range in date of drop was small (7 d), and the crop loads were light.

Natural drop experiment. No multiple regression models explained significantly more variation than simple linear relationships among the variables: plump seed number, aborted seed number, fruit weight, and day of year of drop. Seed number did not affect date of drop for any of the cultivars. Fruit weight increased linearly with increasing number of plump seeds for D (Fig. 4). The periods over which drop occurred for GD, D, and Y were 73, 80, and 94 d, respectively (Fig. 5). Weight of Y fruit increased linearly with day of year of drop (Fig. 5), but the relationship for the other two cultivars, although significant, explained very little variation.

The distribution of number of plump seeds/fruit was similar for Y and GD but quite different for D (Fig. 6). The mode for all three distributions was eight seeds/fruit. The proportion of fruit with no plump seeds was much higher in D (12%) than in the other cultivars (<1%) (Fig. 6).

Discussion

Seed number/fruit based on individual fruit was not a useful predictor of drop for the three cultivars in these experiments. The later drop of 'McIntosh' fruit with more plump seeds (Southwick, 1938a) was a mean response of all fruit dropped over multiple periods of 2–3 d duration. Our study compared individual fruit dropped on a daily basis and should have provided greater resolution of differences, yet no relationship was found. Differences in tree age, cultivar, location, crop load, weather, or other unidentified factors may account for the disparity between these results. Although Southwick (1938a) reported a linear relationship between seeds/fruit and date of drop, the relationship was weak ($r^2 = 0.053$).

Late-season fruit growth, after some fruit had dropped, may explain the greater weight of Y fruit that dropped on later dates. If fruit of all weights have an equal chance of dropping on any given date, we would expect the fruit that drop later to be larger. Fruit that drop early are smaller on Y, but further research is necessary to determine if this is simply a result of the average increase in fruit weight through the season and the longer period over which they dropped. The lack of such a trend in the other cultivars suggests that the largest fruit dropped early and the remaining fruit continued to grow. The D and GD trees also were more vigorous and had lighter crop loads than did the Y trees (4.2 and 4.6 vs. 8.2 fruit/cm² trunk cross-sectional area, respectively). The small Y fruit that dropped early may have been pushed off by other fruit in the same cluster. 'York' has a shorter pedicel than the other two cultivars, and this could make it more susceptible to such losses.

The increase in D fruit weight with increasing plump seed number (Fig. 1) agrees with reports for 'Delicious' (Williams, 1977) and 'Wealthy' (Murneek and Schowengerhdt,

Fig. 4. Relationship between fruit weight and number of plump seeds/fruit for 'Delicious'. Regression line: $Y = 116.53 + 6.181X$; $r^2 = 0.252$, $P \leq 0.0001$, $n = 878$ (Natural-drop expt.).

Fig. 5. Relationship between fruit weight and day of year of drop for three apple cultivars. Regression line for 'York': $Y = -182.911 + 1.029X$; $r^2 = 0.189$, $P \leq 0.0001$, $n = 2052$. Regression lines not shown for 'Golden Delicious' ($r^2 = 0.0033$, $P = 0.028$, $n = 1459$) and 'Delicious' ($r^2 = 0.0062$, $P = 0.020$, $n = 872$) (Natural-drop expt.).

Fig. 6. Frequency distributions for number of plump seeds/fruit for 'Golden Delicious' ($n = 1455$), 'Delicious' ($n = 870$), and 'York' ($n = 2017$) trees (Natural-drop expt.).

1935). Because seed number only explained 25% to 30% of the variability in fruit weight (Figs. 1 and 4), other factors must play a large role in determining fruit size. In the shading experiment, where crop load varied widely (from 0.96 to 4.04 fruit/cm² trunk cross-sectional area), the effect of seed number on weight was nonsignificant. The effect of seed number on fruit size may vary for different locations, years, croploads, or cultivars.

Although fruit maturity was not measured, the early drop of fruit from shaded trees may result from advanced maturity, an effect of reduced crop load. Fruit development and ripening may have proceeded more rapidly with the lighter crop, and the concomitant increase in ethylene production could have stimulated drop (Walsh, 1977).

'Delicious' matures many fruit with no plump seeds (Williams, 1977), but GD and Y

had very few such fruit (Fig. 6). The differences in average number of fruit/tree (727 and 684 for GD and Y vs. 435 for D) may explain the differences in seed distribution. The fruit with no plump seeds may have been retained on D because of the reduced competition among fruit early in the season.

In only two of the seven experiments we conducted was there a significant relationship between fruit weight and seed number, and then seed number only explained 30% and 25% of variability in weight (Figs. 1 and 4). Seed number does not appear to be a useful tool for predicting fruit weight or preharvest drop of the cultivars used in these studies.

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