Detachment Force and Fruit Characteristics of Tabasco Pepper at Several Stages of Development

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Abstract. Field and greenhouse studies examined the fruit detachment force (FDF) and fruit and pedicel characteristics of two lines of tabasco pepper (*Capsicum frutescens* L.) at several stages of maturity. The detachment force of red-mature 'McIlhenny Select' fruit at the calyx-fruit detachment area was lower than that of less mature fruit stages. The force required to detach red-mature Hard Pick (HP) tabasco fruit was higher than that of red-mature 'McIlhenny Select' fruit in the field and greenhouse. The fruit detachment force of red field-grown HP fruit was higher, and in the greenhouse was lower, than that of green or breaker fruit. HP fruit of all maturity stages, except red-mature, separated similarly to 'McIlhenny Select' fruit with little or no fruit tissue attached to the calyx. Fruit detachment force was not correlated with any fruit or pedicel characteristics studied.

Capsicum frutescens includes tabasco pepper, the second most important species in terms of value in the United States (Andrews, 1995). The U.S. processed pepper market was \$240 million in 1991, with the retail cayenne/tabasco sauce market estimated to be \$70 million (personal communication, James Lusk, Petoseed Co., Saticoy, Calif.). The increase in the sauce market was 10% to 15% per year in the early 1990s and is expected to increase with heightened interest in ethnic foods.

Most pepper cultivars that are grown in the United States are considered nondeciduous and require more effort in fruit removal than wild-type peppers. Peppers are still primarily hand harvested. This fact is a major consideration for growers of fruit destined for processing, because the value of the raw fruit is less than that for the fresh market, and the greatest single expense is often harvest costs. Fruit quality for the sauce industry, however, is equally important as for the fresh market; there is a low tolerance for pedicels and calyx that often adhere to fruit. Understanding the process of pepper fruit abscission or detachment is important for pepper varietal development and cultural practice improvement.

Early research reported a deciduous ripe pepper fruit characteristic: separation of ripe fruit occurred at the calyx (Smith, 1951). The deciduous characteristic was determined to be inherited as a single dominant gene. Other

researchers investigating ease of fruit detachment at the fruit-pedicel junction reported that fruit detachment force (FDF) positively correlated with fruit length, diameter, and weight; FDF was a heritable characteristic (Werner and Honma, 1980). In addition, research has been conducted to investigate pepper fruit separation at the pedicel-stem junction. Marshall (1979) reported that a small-diameter pedicel scar at the point of attachment to the stem correlated with easier pepper fruit removal and Stall (1973) demonstrated that FDF correlated positively with stem scar diameter. Other research indicated that, in general, FDF at the pedicel-stem correlated positively with pedicel and fruit length, and with fruit diameter (Setiamihardja and Knavel, 1990). All of the research outlined above was conducted with *C. annuum*. Mature tabasco fruit normally separate easily at the calyx-fruit detachment area, leaving the green calyx and pedicel attached to the plant. Little research has been conducted to investigate pepper fruit detachment in this pepper species (Conrad and Sundstrom, 1987).

The objectives of this study were to quantify the force required to separate pepper fruit from the calyx for two lines of tabasco pepper that differ in ease of fruit detachment and to examine the influence of fruit maturity on detachment force and fruit characteristics. Knowledge concerning the effect of fruit maturity on FDF and fruit characteristics in various pepper genotypes would be useful in conducting experiments investigating pepper fruit detachment and, ultimately, in developing pepper cultivars for mechanical harvest.

Materials and Methods

Plant material. Plants that exhibited easy or hard fruit detaching characteristics were removed from a heterogeneous population of

tabasco pepper in a production field on Avery Island, La. These plants were then grown in pots in the greenhouse. One plant each with easy or hard fruit detachment characteristics was selected and seeds collected from red-mature fruit for future research studies. The HP line requires a greater force to remove fruit from the pedicel, a characteristic that is indigenous in the plant population at low levels (<10%, personal observation). The 'McIlhenny Select' line is typical of the majority of the plant population; mature fruit separate readily at harvest.

Field study. 'McIlhenny Select' and HP tabasco seed were sown in 72-cell trays (cell size $3.8 \times 3.8 \times 5.7$ cm, 4.8 cm³) filled with commercial soilless mix (Metromix 350, W.R. Grace and Co., Cambridge, Mass.) and placed in the greenhouse. Four-week-old seedlings were then transplanted into black plastic-mulched plots at a 0.3-m in-row spacing on 2.2 m centers at the Burden Research Station in Baton Rouge, La., in Spring 1993. Individual plots consisted of one plant with fruit harvested twice. The soil used was an Olivier silt loam (fine silty, mixed thermic, Aquic Fragiudalfs). Plots received preplant fertilizer (8N–10.4P–20K) at 600 kg·ha⁻¹ banded in the row and an additional N application (NH_4NO_3 , N at 67 kg·ha⁻¹) 8 weeks after transplanting. Recommended pepper plant establishment and pest management practices were followed (Boudreaux, 1992). Overhead irrigation was applied as needed throughout the season.

Fruit color was determined using a standard color system (Munsell Book of Color, 1976). Yellow-orange mature-sized fruit (breaker) (2.5Y, 7/10) were tagged and 3 days later five fruit of each developmental stage [green-mature (7.5Y, 7/10); breaker; and red-mature (7.5R, 4/14), previously tagged as breaker], were selected randomly and removed by cutting the pedicel at the stem attachment area. FDF was measured, using a push-pull force gauge (John Chatillon and Sons, Greensboro, N.C.) modified according to Werner and Honma (1980) (Fig. 1), by slowly pulling the fruit by hand parallel to the fruit axis until the fruit and the pedicel separated. FDF was measured as kilogram force and then converted to Newtons. Fruit length and width and pedicel length were measured with vernier calipers, and each fruit was weighed.

Greenhouse study. 'McIlhenny Select' and HP tabasco seed were sown in cell trays in the greenhouse as described above. Four-week-old seedlings were then transplanted in Winter 1993–94 into 11.4-L pots filled with medium (Metromix 700, W.R. Grace and Co.) supplemented with dolomitic limestone (6.3 g·L⁻¹; Easy Lime, Sylacauga, Ala.), micronutrients (780 mg·L⁻¹ Micromax, Grace Sierra, Milpitas, Calif.) and slow-release fertilizer (4.7 g·L⁻¹, Osmocote 14N–6.2P–11.6K, Scott Sierra, Marysville, Ohio). Plants were irrigated twice daily, or as needed, to maintain plants above the wilting point. Soluble fertilizer (20N–8.7P–16.7K, Masterblend; Vaughn Products, Chicago) was applied biweekly. Individual plots consisted of one plant and fruit were harvested three times. In addition to the three stages of

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Fig. 1. Force gauge used to measure fruit detachment force (FDF) of tabasco pepper. FDF was determined by slowly pulling the fruit by hand parallel to the fruit axis until the fruit and the pedicel separated.

fruit maturity described above, immature-green was used in the greenhouse study. This stage consisted of immature yellow-green fruit (10Y, 6/8) at least 0.5 cm long. FDF and fruit and pedicel characteristics were determined as described for the field study.

Statistical analysis. A randomized complete-block design was used with three replications for the field and four replications for the greenhouse studies. Analysis of variance was performed on FDF and fruit characteristic data using Proc-Mixed (SAS Institute, Cary, N.C.). Bonferroni-corrected contrasts were performed to determine the effect of the two pepper lines, and maturity and simple correlation analysis was performed to investigate the relationship of FDF and fruit characteristics.

Results

Field study. The FDF for red-mature 'McIlhenny Select' fruit was much lower than that for green or breaker fruit (Table 1); it was similar for the later two stages. The fruit of all three maturity stages separated cleanly without tearing. Fruit length and width were not affected by fruit maturity for the three stages studied. In contrast, 'McIlhenny Select' fruit mass and pedicel length were influenced by fruit maturity. Green-mature fruit mass was lower than that of either breaker or red 'McIlhenny Select' fruit. Fruit mass did not differ between red and breaker fruit. Pedicel length of red fruit was longest and that of breaker fruit was longer than that of green-mature fruit.

There were differences in the force necessary to detach HP fruit of differing maturities; the FDF for red-mature HP fruit was highest and the FDF of breaker fruit was higher than that of green HP fruit (Table 1). Very few red

HP fruit separated cleanly at the calyx; most of these separated with fruit tissue attached to the calyx (Fig. 2). In contrast, green and breaker fruit separated cleanly. All the HP fruit and pedicel characteristics measured were affected by fruit maturity. HP breaker fruit were shorter than green-mature or red fruit, but fruit length of red and green-mature stages was similar. Red fruit was wider than fruit of the other stages while breaker fruit mass was lower than that of the other stages. Pedicels of red HP fruit were longer than those of the green-mature or breaker-stage fruit.

'McIlhenny Select' and HP fruit differed in FDF and fruit characteristics within a particular maturity stage. Fruit detachment force of red HP fruit was nearly 10 times higher than that of red 'McIlhenny Select' fruit. FDF of green and breaker fruit of the two lines, however, did not differ. Green and red HP fruit were longer than 'McIlhenny Select' fruit of the same maturity. Fruit length of breaker fruit did not differ between lines, while fruit width was similar for both lines at any maturity stage. Fruit weight for green HP fruit, however, was higher than that for green 'McIlhenny Select' fruit. The lines did not differ in pedicel length.

Greenhouse study. The force required to remove red-mature fruit was lower and the FDF for green-mature was higher than that for the other stages of 'McIlhenny Select' fruit (Table 2). The FDF of immature-green and breaker 'McIlhenny Select' fruit was similar. FDF of red and immature-green HP fruit was lower than that of green-mature and breaker HP fruit. The FDF of red fruit was similar to that of immature-green fruit and the FDF of green and breaker fruit was similar for the HP line. In comparing the two lines, the FDF of breaker and red-mature 'McIlhenny Select' fruit was lower than that of HP fruit of the same maturity. 'McIlhenny Select' fruit length was affected by maturity; green-mature and red fruit were longer than breaker and immature-green fruit. Red HP fruit was longer than the other fruit stages except green-mature. Breaker and red HP fruit were longer than 'McIlhenny Select' fruit of the same maturity, while green-mature fruit length did not vary with the line. Green-mature fruit was widest for both lines, while breaker and red fruit width were similar. Fruit width did not differ between lines. Fruit mass varied with maturity; green-mature fruit mass for both lines was highest, and immature-green fruit mass was the lowest. Only breaker fruit mass differed between lines; HP breaker fruit weighed more than that of 'McIlhenny Select'. 'McIlhenny Select' red fruit had longer pedicels than immature and breaker fruit for this line. Pedicel length did not vary with maturity stage for HP and did not differ between the two lines.

Discussion

The visible signs of fruit separation for all maturity stages were similar for the tabasco lines, with the exception of HP red fruit, although there were differences in FDF. These

Table 1. Fruit detachment force and fruit characteristics of two tabasco pepper lines at three fruit developmental stages in a field study.^z

Line	Fruit maturity	Detachment force ^y (N)	Fruit			Pedicel length (mm)
			Length (mm)	Width (mm)	Mass (g)	
McIlhenny Select	Green-mature	15.7	27.1	8.0	0.63	23.1
	Breaker	16.3	26.3	7.9	0.74	24.5
	Red-mature	2.5	26.3	7.9	0.74	27.7
Contrasts	Maturity within McIlhenny Select	***	NS	NS	**	***
	Green-mat. vs. breaker	NS	NS	NS	**	*
	Breaker vs. red-mat.	***	NS	NS	NS	***
	Green-mat. vs. red-mat.	***	NS	NS	**	***
HP	Green-mature	14.5	29.4	7.7	0.81	23.5
	Breaker	17.7	27.0	7.3	0.69	24.0
	Red-mature	22.1	28.4	8.0	0.80	26.2
Contrasts	Maturity within HP	***	***	***	**	***
	Green-mat. vs. breaker	**	***	*	**	NS
	Breaker vs. red-mat.	***	**	***	**	***
	Green-mat. vs. red-mat.	***	NS	*	NS	***
Contrasts	Lines within maturity	***	*	*	***	NS
	Green-mature	NS	*	NS	***	NS
	Breaker	NS	NS	NS	NS	NS
	Red-mature	***	*	NS	NS	*

^zResults are pooled over three replications and two harvests.

^yForce required to detach fruit from the calyx-pedicel, measured using a push-pull force gauge; scale 0.25 to 24.5 N.

NS, *, **, *** Orthogonal contrasts nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

results suggest that similar physiological and/or structural changes occur in the fruit separation zone with maturity in both lines. At the red-mature stage, however, these lines differed in the visual aspects of the separation zones. An understanding of the anatomical and biochemical changes associated with tabasco fruit maturity and ripening, and in particular the detachment zone, would be useful in understanding pepper fruit detachment.

Other researchers have investigated the influence of genotype on FDF of green-mature fruit of *Capsicum annuum* L. (Setiamihardja and Knavel, 1990; Werner and Honma, 1980). These researchers did not report any visible differences in the fruit separation area, such as is evident with tabasco. Research on cayenne red-mature fruit indicated differences between lines in ease of fruit detachment (Gersch et al., 1994). One line, identified as hard to detach, did not separate cleanly but tore at the calyx-fruit detachment area.

Fruit characteristics for a particular tabasco line differed due to maturity, with the exception of 'McIlhenny Select' fruit length and width in the field study and HP pedicel length in the greenhouse study. There is no explanation for the HP breaker fruit in the field study having the lowest fruit mass, shortest length, and narrowest width. There was no correlation of FDF and fruit characteristics in either the field or greenhouse studies (data not shown). Fruit mass, however, positively correlated with fruit length ($r = 0.86$) and width ($r = 0.78$) in the greenhouse. These results suggest that using fruit or pedicel characteristics to breed for ease of fruit detachment would not be feasible. Other researchers have indicated that FDF in *C. annuum* was positively correlated with fruit length, width, and mass (Setiamihardja and Knavel, 1990; Werner and Honma, 1980). However, these researchers investigated different separation areas: Werner and Honma (1980) at the pedicel-calyx junction and Setiamihardja and Knavel (1990) at the pedicel-stem.

The results of this study demonstrate that FDF varies with fruit development in HP and 'McIlhenny Select' tabasco peppers and that the lines differ in FDF. Studies specifically designed to investigate the genetic control of FDF in tabasco pepper, the role of plant growth regulators, and the interactive effects of fruit maturity on pepper fruit detachment are warranted. These two tabasco lines appear to be appropriate plant materials to investigate these variables.

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Fig. 2. Pedicels and detached red-mature fruit of 'McIlhenny Select' (left) and Hard Pick (HP) tabasco peppers (right). Arrows indicate fruit tissue attached to the calyx of the HP line.

Table 2. Fruit detachment force and fruit characteristics of two tabasco pepper lines at four developmental stages in a greenhouse study.²

Line	Fruit Maturity	Detachment force ³ (N)	Fruit			Pedicel length (mm)
			Length (mm)	Width (mm)	Mass (g)	
McIlhenny Select	Immature-green	10.7	23.2	6.5	0.47	25.0
	Green-mature	16.2	29.6	8.5	0.91	26.5
	Breaker	9.7	27.0	7.8	0.72	25.2
	Red-mature	0.6	30.4	7.9	0.89	31.8
Contrasts	Maturity within McIlhenny Select	***	***	***	***	*
	Immature vs. green-mat.	***	***	***	***	NS
	Immature vs. breaker	NS	***	***	***	NS
	Immature vs. red-mat.	***	***	***	***	*
HP	Green-mat. vs. breaker	***	***	***	***	NS
	Green-mat. vs. red-mat.	***	NS	**	NS	NS
	Red-mat. vs. breaker	***	***	NS	***	*
	Immature-green	10.4	22.6	6.6	0.44	25.1
HP	Green-mature	15.3	31.1	8.2	0.97	26.5
	Breaker	16.2	32.2	7.9	0.90	25.1
	Red-mature	8.9	32.9	7.7	0.91	24.9
Contrasts	Maturity within HP	***	***	***	***	NS
	Immature vs. green-mat.	***	***	***	***	NS
	Immature vs. breaker	***	***	***	***	NS
	Immature vs. red-mat.	NS	***	***	***	NS
HP	Green-mat. vs. breaker	NS	NS	*	NS	NS
	Green-mat. vs. red-mat.	***	**	**	NS	NS
	Red-mat. vs. breaker	***	NS	NS	NS	NS
	Lines within maturity	***	***	NS	***	NS
Contrasts	Immature-green	NS	*	NS	NS	NS
	Mature-green	NS	NS	NS	NS	NS
	Breaker	***	***	NS	***	NS
	Red-mature	***	***	NS	NS	*

²Results are pooled over four replications and three harvests.

³Force required to detach fruit from the calyx-pedicel, measured using a push-pull force gauge; scale 0.25 to 24.5 N.

NS, *, **, *** Orthogonal contrasts nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.