Association of Pedicel Length and Diameter with Fruit Length and Diameter and Ease of Fruit Detachment in Pepper

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Abstract. Genetic correlations for pedicel length and diameter, fruit length and diameter, and fruit detachment force (FDF) were determined in three pepper (*Capsicum annuum* L.) families from crosses of 'Serrano Chili' (low FDF) with three cultivars ('Anaheim Chili', 'Keystone Resistant Giant', and 'Red Cherry Small') characterized by high FDF and different fruit characteristics. Pedicel and fruit length means of F₁ generations were nearly intermediate, while pedicel and fruit diameter means were shifted toward 'Serrano Chili'. Progeny distributions in F₂ generations were continuous and F₂ means slightly less than the F₁ means. Generation mean analyses indicated gene effects for pedicel and fruit length to be mostly additive. Gene effects for pedicel and fruit diameter were also mostly additive. Pedicel length was positively correlated genetically with fruit length, and pedicel diameter was positively correlated with fruit diameter. FDF means were positively correlated with pedicel and fruit length and diameter in most segregating generations. In BCP₁ ('Serrano Chili' × 'Red Cherry Small'), FDF was negatively correlated with pedicel and fruit length. Pendant fruit in BCP₁ ('Serrano Chili' × 'Red Cherry Small') were longer and narrower than upright fruit and FDF decreased with increased length of both pedicel and fruit.

Pepper fruit do not have an abscission layer in pedicels as do tomatoes (Villalon and Bryan, 1970), and pedicel attachment is very strong in cultivars with large fruit. Oftentimes, there is tearing of the pedicel and considerable stem breakage even in hand-harvesting. The deciduous character that controls fruit separation from the calyx (Smith, 1951) would be undesirable because fruit would fall to the ground. The gene also causes fruit softening.

Marshall (1979) found in machine harvesting cultivars of diverse fruit characteristics that fruit of 'Serrano Chili' were the easiest to remove because of a small-diameter pedicel scar at the point of attachment to the stem. Stoll (1973) found in removing pepper fruit that the pull of force at the pedicel attachment site was correlated to the stem scar diameter. Werner and Honma (1980) reported that easy fruit removal was positively correlated with fruit length, diameter, and weight and that fruit detachment force was an inheritable character.

There is very little information on pedicel characters in pepper. Deshpande (1933) reported that a short pedicel is dominant to long and Odland (1948) found pedicels of pendant fruit to be longer than those of erect fruit, especially for heavy fruit. No data are available on pedicel diameter.

Factors that control fruit length and diameter may also control pedicel length and diameter, and both are possibly related to

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ease of fruit detachment. Understanding the relationship between pedicel and fruit characters should be of value in a breeding program to develop genotypes for easy fruit removal in harvesting. The objectives of these studies were to determine: 1) gene action for the inheritance of pedicel length, diameter, and length : diameter ratios; 2) their association with fruit length, diameter, and length : diameter ratios; and 3) their association with the force required to separate fruit from the stem in three pepper families with various pedicel sizes, fruit sizes and shapes.

Materials and Methods

Three pepper families were produced, each with the F_1 , F_2 , BCP_1 , and BCP_2 populations. 'Serrano Chili' (Ser), with pendant fruit orientation easily removed by machine, was used as the common parent (P_1) in each family. It was crossed to 'Red Cherry Small' (Cher), upright fruit orientation difficult to remove; 'Keystone Resistant Giant' (KRG), bell-type fruit difficult to remove; and to 'Anaheim Chili' (Anh), long and pendant fruit also difficult to remove by machine.

The parental cultivars were grown in a greenhouse and hand-selved for three generations before crossing. Plants of each generation for each family were grown in field plots in a randomized complete-block design with three replications. Within each replication, there were 36 plants of each parent and F_1 , and 72 plants of each backcross and F_2 generation per family. Plants were spaced 0.6 m apart in rows spaced 1.1 m apart. Plants were grown by recommended practices for Kentucky (Roberts et al., 1980).

Data were collected during September and October on red (ripe) fruit. Pedicel length was measured as the distance between the points of attachment to the stem and to the fruit. Pedicel diameter was recorded at the point of attachment to the stem or stem scar because this is the place of separation for 'Serrano Chili' fruit. Fruit length was measured as the distance from pedicel attachment to its apex. Fruit diameter was measured at its maximum width. All measurements were made with vernier calipers.

Fruit detachment force (FDF) was measured with an Ametek force recording device (Hunter Spring Division, Hatfield, Pa.). An alligator clamp was welded to the pull or push rod of the device for firmly grasping the pedicel. The part of the stem to which the fruit was attached was held as firmly as possible with one hand, while the other hand was used to pull the device. The clamp was attached perpendicular to the pedicel and the direction of pull was perpendicular to the pedicel's orientation. Three fruits were randomly sampled per plant for measurements.

Data were analyzed separately for each family for gene action, analysis of variance, and correlations of pedicel characters with fruit characters and of FDF with pedicel and fruit characters. Partitioning of mean squares and mean products in a multivariate analysis of variance allowed calculation of among-plant and within-plant variance and covariance components. Standard errors of genetic correlations were calculated according to procedures of Mode and Robinson (1959). A genetic correlation was considered significant when it exceeded the standard error and highly significant when it was twice the standard error.

An estimate of gene effects was determined by generation mean analysis on plant means according to Hayman (1958), Gamble (1962a, 1962b), and Mather and Jinks (1971). Both the F_2 -metric and F -infinity models (Van Der Veen, 1959) were fitted by the least-squares method (Fuller and Battase, 1973) because of among-plot and within-plot error variance components.

Results

Generation means and gene action for pedicel length and diameter. F_1 means (Table 1) for pedicel length for each family, except for Ser $\times$ KRG, were nearly intermediate to that of the parents. The F_1 Ser $\times$ KRG mean was very similar to the P_2 parent. Pedicel diameter means (Table 1) for F_1 populations in each family were closer to the P_1 than to the P_2 parent. Progeny distributions (not shown) for pedicel length and diameter segregation were continuous. F_2 means for pedicel length were close to the F_1 means, with BCP_1 means shifted toward P_1 and BCP_2 means about intermediate to parental means, except for Ser $\times$ KRG. The BCP_2 Ser $\times$ KRG population exhibited transgressive segregation (not shown). F_2 means for pedicel diameter were also similar to F_1 means, with the BCP_1 means strongly shifted toward P_1 . BCP_2 means for pedicel diameter were intermediate to parental means.

Differences among pedicel length and diameter means were mostly due to additive gene action (Table 2), but there were significant dominance effects in all families. Epistasis was mostly additive $\times$ additive for pedicel length in Ser $\times$ Anh and Ser $\times$ KRG, and additive $\times$ dominance for pedicel diameter in Ser $\times$ KRG.

Generation means and gene action for fruit length and diameter. Fruit length and diameter means (Table 1) for F_1 populations were intermediate, as were pedicel means, to parental means in two families. Fruit length mean of F_1 Ser $\times$ Anh and diameter mean of F_1 Ser $\times$ KRG were closer to P_1 than P_2 . F_2 means were generally close to the F_1 means. The narrower PI fruit type was found in BCP_1 and F_2 of Ser $\times$ Anh, in all segregating generations of Ser $\times$ Cher, and in BCP_1 of Ser $\times$ KRG. The wider P_2 -type fruit was not recovered in F_2 Ser $\times$ KRG.

Most of the gene action was additive for both fruit length and diameter (Table 2). There was high dominance for fruit length in Ser $\times$ Anh, but a low one for diameter, whereas dominance was high for diameter in Ser $\times$ KRG. Epistasis was evident for

Table 1. Means for pedicel length (PL), pedicel diameter (PD), fruit length (FL), fruit diameter (FD), and fruit detachment force (FDF) for parents and generations of three pepper families.²

Generation	PL (cm)	PD (cm)	FL (cm)	FD (cm)	FDF (kg)
<i>Serrano Chili x Anaheim Chili</i>					
P_1	2.57 e	0.20 e	3.95 f	1.30 e	0.45 e
P_2	5.19 a	0.71 a	17.83 a	3.69 a	2.22 a
F_1	3.67 b	0.35 c	8.43 c	2.21 c	0.73 d
BCP_1	3.04 d	0.31 d	6.45 e	1.89 d	0.68 d
BCP_2	3.70 b	0.47 b	9.71 b	2.67 b	1.14 b
F_2	3.30 c	0.36 c	7.89 d	2.19 c	0.82 c
<i>Serrano Chili x Red Cherry Small</i>					
P_1	2.44 a	0.21 f	3.91 a	1.30 f	0.45 e
P_2	1.58 e	0.60 a	2.16 e	2.87 a	1.82 a
F_1	2.13 c	0.32 d	2.88 c	2.31 c	0.68 c
BCP_1	2.33 b	0.27 e	3.47 b	1.87 e	0.50 d
BCP_2	1.89 d	0.45 b	2.71 d	2.51 b	1.04 b
F_2	2.18 c	0.35 c	2.95 c	2.25 d	0.68 c
<i>Serrano Chili x Keystone Resistant Giant</i>					
P_1	2.47 f	0.21 f	3.91 e	1.33 e	0.50 f
P_2	3.04 b	1.03 a	7.89 a	6.78 a	3.18 a
F_1	2.95 c	0.37 d	5.92 c	2.85 c	0.77 d
BCP_1	2.63 e	0.29 e	4.81 d	1.96 d	0.59 e
BCP_2	3.15 a	0.64 b	7.19 b	4.00 b	1.36 b
F_2	2.76 d	0.43 c	5.93 c	2.88 c	0.86 c

²Means separation within columns within families by Duncan's multiple range test, $P = 0.05$.

Table 2. F values of gene action for pedicel length and diameter and fruit length and diameter for three pepper families.

		Families					
Gene action	df	Ser x Anh ^z		Ser x Cher ^y		Ser x KRG ^x	
		Length	Diam	Length	Diam	Length	Diam
<i>Pedicel</i>							
Additive (Add)	1	153.19**	448.33**	198.12**	416.55**	47.00**	1188.50**
Dominance (Dom)	1	4.00	33.42**	5.26*	34.74**	2.27	199.53**
Add × Add	1	9.11**	2.75	6.53*	0.01	0.69	22.88**
Add × Dom	1	6.73*	11.01**	0.14	0.93	1.51	5.33*
Dom × Dom	1	1.14	1.78	0.00	0.49	1.01	0.13
Pooled epistasis	3	5.66*	5.18*	2.22	0.48	1.07	9.43**
<i>Fruit</i>							
Additive (Add)	1	356.67**	392.41**	942.56**	1302.84**	1240.88**	7021.56**
Dominance (Dom)	1	22.59**	6.38*	8.56*	39.03**	0.00	719.75**
Add × Add	1	11.54**	0.61	0.96	2.98	0.00	149.60**
Add × Dom	1	19.62**	6.16*	0.80	3.67	3.44	28.11**
Dom × Dom	1	1.86	0.26	4.81*	0.46	0.45	8.57*
Pooled epistasis	3	11.01**	2.35	2.50	2.37	1.30	62.09**

^z‘Serrano Chili’ x ‘Anaheim Chili’.

^y‘Serrano Chili’ x ‘Red Cherry Small’.

^x‘Serrano Chili’ x ‘Keystone Resistant Giant’.

*,**Significant at $P = 0.05$ and 0.01 , respectively.

fruit length in Ser x Anh and for fruit diameter in Ser x KRG, with all three epistatic components significant for diameter in Ser x KRG.

Generation means and gene action for FDF. FDF for ‘Serrano Chili’ (P_1 in all cases) was the lowest, while the mean for ‘Keystone Resistant Giant’ (P_2 in Ser x KRG) was the highest (Table 1). The F_1 , F_2 , and BCP means for FDF were similar within each family and strongly shifted toward the P_1 mean. Backcrossing to P_1 in each family shifted FDF means to about intermediate to those of the parents. Many of the F_2 progeny were in the low FDF range, and only few were in the low range of the high FDF parent for F_2 Ser x Anh and F_2 Ser x Cher. No high FDF types were recovered in the F_2 of Ser x KRG and only $\approx 10\%$ of the BCP₂ individuals of this family were within the high FDF range.

In BCP₂ Ser x Cher, pendant fruits and pedicels grew longer and narrower than upright fruits (Table 3), and FDF was greater for upright fruit than for pendant fruit. In the F_2 , means of fruit and pedicel length and fruit diameter of pendant and upright fruit were similar, and the required FDF was slightly higher for upright than for pendant fruit.

Table 3. Means for fruit and pedicel length, fruit and pedicel diameter, and fruit detachment force (FDF) for pendant and upright fruits of BCP₂ and F_2 generations of ‘Serrano Chili’ x ‘Red Cherry Small’ pepper family.

Fruit orientation	No. plants observed	Length (cm)		Diam (cm)		FDF (kg)
		Fruit	Pedicel	Fruit	Pedicel	
<i>BCP₂ generation</i>						
Pendant	97	2.83	1.94	2.40	0.40	0.80
Upright	46	2.50	1.79	2.69	0.52	1.38
Significance		**	**	**	**	**
<i>F₂ generation</i>						
Pendant	183	2.98	2.18	2.23	0.34	0.64
Upright	63	2.86	2.18	2.27	0.38	0.82
Significance		NS	NS	NS	*	*

NS,*,**Nonsignificant or significant F value at $P = 0.05$ and 0.01 , respectively.

Differences among FDF means were mostly due to additive gene action (Table 4), but there were significant dominant, additive x additive, and additive x dominant effects in all families. There was also a significant dominant x dominant effect in Ser x KRG. The pooled epistasis was significant in all families.

Genetic correlations of pedicel length and diameter with fruit length and diameter. Pedicel length and pedicel diameter were positively correlated with fruit length and fruit diameter, respectively, in all segregating populations (Table 5). Pedicel diameter was positively correlated with fruit length in BCP₁ and F_2 populations of Ser x Anh and Ser x KRG. Pedicel length was positively correlated with fruit diameter in BCP₁ Ser x Anh, BCP₁ Ser x KRG, BCP₂ Ser x KRG, and F_2 Ser x Anh, but the correlation was negative in BCP₂ Ser x Cher.

Pedicel length : diameter ratios were positively correlated with fruit length : diameter ratios in all segregating generations of the three families, except BCP₁ Ser x Anh (Table 6).

Genetic correlations of fruit detachment force with pedicel and fruit characters. FDF was correlated more positively with pedicel diameter and fruit diameter than with pedicel length and fruit length (Table 7). In the Ser x Cher family, FDF was pos-

Table 4. F values of gene actions for fruit detachment force in three pepper families.

Gene action	df	Families		
		Ser x Anh ^z	Ser x Cher ^y	Ser x KRG ^x
Additive	1	252.76**	543.78**	993.60**
Dominant	1	57.97**	142.29**	349.59**
Additive x additive	1	9.43**	40.32**	86.79**
Additive x dominant	1	17.09**	6.53*	51.03**
Dominant x dominant	1	0.03	0.75	7.18**
Pooled epistasis	3	8.85**	15.87**	48.33**

^z‘Serrano Chili’ x ‘Anaheim Chili’.

^y‘Serrano Chili’ x ‘Red Cherry Small’.

^x‘Serrano Chili’ x ‘Keystone Resistant Giant’.

*,**Significant at $P = 0.05$ and 0.01 , respectively.

Table 5. Genetic correlation coefficients for association of pedicel length (PL) and pedicel diameter (PD) with fruit length (FL) and fruit diameter (FD) for segregating generations of pepper families.

Gener- ation	Pedicel character	Families					
		Ser x Anh ^z		Ser x KRG ^y		Ser x Cher ^x	
		FL	FD	FL	FD	FL	FD
BCP ₁	PL	0.66**	0.47**	0.46**	0.42**	0.65**	-0.20
	PD	0.90**	0.83**	0.48**	0.73**	-0.18	0.65**
BCP ₂	PL	0.41**	0.04	0.62**	0.52**	0.71**	-0.60**
	PD	0.11	0.63**	0.84**	0.93**	-0.52**	0.88**
F ₂	PL	0.52**	0.42**	0.16	0.07	0.48**	-0.09
	PD	0.25*	0.73**	0.42**	0.68**	0.10	0.45**

^zSerrano Chili' x 'Anaheim Chili'.

^ySerrano Chili' x 'Keystone Resistant Giant'.

^xSerrano Chili' x 'Reel Cherry Small'.

*,**Significant at $P = 0.05$ and 0.01 , respectively.

Table 6. Genetic correlation coefficients for association of pedicel length : diameter ratio with fruit length : diameter ratio for pepper families.

Generation	Families		
	Ser x Anh ^z	Ser x KRG ^y	Ser x Cher ^x
BCP ₁	-0.16	0.22*	0.60**
BCP ₂	0.49**	0.85**	0.86**
F ₂	0.43**	0.26**	0.34**

^zSerrano Chili' x 'Anaheim Chili'.

^ySerrano Chili' x 'Keystone Resistant Giant'.

^xSerrano Chili' x 'Red Cherry Small'.

*,**Significant at $P = 0.05$ and 0.01 , respectively.

Table 7. Genetic correlation coefficients for association of fruit detachment force with pedicel length (PL), pedicel diameter (PD), fruit length (FL), fruit diameter (FD), pedicel length: diameter ratio (PR), and fruit length : diameter ratio (FR) for segregating generations of pepper families.

Generation	PL	PD	PR	FL	FD	FR
<i>Serrano Chili x Anaheim Chili</i>						
BCP ₁	-0.17	-0.16	0.01	-0.18	-0.10	-0.11
BCP ₂	0.02	0.24*	-0.18	0.19	0.18	0.08
F ₂	0.25*	0.30*	-0.10	0.15	0.25*	-0.05
<i>Serrano Chili x Red Cherry Small</i>						
BCP ₁	-0.31*	0.58**	-0.53**	-0.25*	0.52**	-0.36**
BCP ₂	-0.43**	0.69**	-0.56**	-0.41**	0.53**	-0.51**
F ₂	-0.04	0.33**	-0.15	-0.03	0.54**	-0.37**
<i>Serrano Chili x Keystone Resistant Giant</i>						
BCP ₁	0.35**	0.17	0.16	0.17	0.37**	-0.19*
BCP ₂	0.37**	0.85**	-0.84**	0.77**	0.81**	-0.64**
F ₂	0.04	0.41**	-0.26*	0.12	0.26*	-0.13

*,**Significant at $P = 0.05$ and 0.01 , respectively.

itively correlated with pedicel and fruit diameter in BCP₁, BCP₂, and F₂; negatively correlated with pedicel and fruit length in BCP₁ and BCP₂; negatively correlated with pedicel length : diameter ratio in BCP₁; and negatively correlated with fruit length: diameter ratios in BCP₁ and BCP₂. In BCP₂ and F₂ of Ser x Cher, FDF correlated positively with diameter of pendant and upright fruit (Table 8). There was no correlation of FDF with length of upright fruit in either generation of Ser x Cher, but FDF correlated negatively with pedicel and fruit length of pendant fruit in BCP₂.

In Ser x KRG, FDF was positively correlated with length and

Table 8. Phenotypic correlation coefficients for association of fruit detachment force with pedicel length (PL), fruit length (FL), pedicel diameter (PD), and fruit diameter (FD) for pendant and upright fruits of BCP₂ and F₂ generations of 'Serrano Chili' x 'Red Cherry Small' pepper family.

Fruit orientation	PL	FD	FL	FD
<i>BCP₂</i>				
Pendant	-0.24**	0.54**	-0.30**	0.45**
Upright	-0.09	0.53**	-0.05	0.37**
<i>F₂</i>				
Pendant	-0.02	0.32**	-0.03	0.23**
Upright	-0.17*	0.44**	0.08	0.26**

*,**Significant at $P = 0.05$ and 0.01 , respectively.

diameter of pedicel and fruit in BCP₂ and with fruit diameter in BCP₁, but negatively correlated with ratios in BCP₂ (Table 7). In F₂ Ser x Anh, FDF correlated positively with pedicel length, pedicel diameter, and fruit diameter.

Discussion and Conclusions

The continuous distribution of pedicel and fruit length in segregating populations, similarity of F₂ and F₁ means, and the high additive gene action indicate quantitative inheritance for these characters, as reported for fruit length (Dempsey, 1960; Deshpande, 1933; Kaiser, 1935; Khambanonda, 1950; Legg and Lippert, 1966; McArdle and Bouwkamp, 1983; Peterson, 1959; Werner and Honma, 1980). F₁ and F₂ means for pedicel and fruit diameter shifted toward the P₁ mean, with mostly additive effects for small-diameter pedicels and fruit.

Significant positive genetic correlations of pedicel length with fruit length, pedicel diameter with fruit diameter, and pedicel length : diameter ratios with fruit length : diameter ratios indicates that the gene system that controls pedicel length and diameter is the same as for fruit length and diameter.

In hand harvesting pepper fruit, we believe that FDF is mainly a function of the gene system that involves pedicel characters in the nondeciduous fruit genotypes. In machine harvesting, where fruit movement occurs, pedicel and fruit characters apparently would be involved in FDF. Fruit weight was positively correlated with FDF, as reported by Werner and Honma (1980), and would be a factor in ease of fruit removal in machine harvesting.

Gene action for FDF means was mostly additive, but with considerable dominance and epistasis. F₁ and F₂ means were similar and strongly shifted toward P₁. These data agree with the findings by Werner and Honma (1980), who also claimed that selection for individuals with low FDF would be possible.

Based on the genetic correlation data, the genes for fruit characters appear to be pleiotropic for pedicel characters. Selection for long fruit in segregating populations should increase the probabilities for increased pedicel length and diameter and FDF, except in BCP₂ Ser x Cher. In contrast, selection for longer fruit within BCP₂ Ser x Cher should decrease pedicel diameter and FDF. Selection for greater diameter fruit in all families should tend to increase pedicel diameter and FDF. Since there were no correlations of FDF with fruit characters in BCP₂ Ser x Anh, and since 12% of the individuals were within the high FDF range, progress probably can be made in a backcrossing program for low FDF in 'Anaheim'-type fruit. There appears to be considerable genetic variation within F₂ populations for selecting long pedicels of small diameter while improving fruit size and shape.

The negative phenotypic correlation coefficients of FDF with pedicel and fruit length in BCP₂ and F₂ of Ser × Cher (Table 7) were due to segregates with upright and pendant fruit orientation. This character is controlled by a single gene. (Kaiser, 1935; Odland, 1948), but Odland (1948) found heavy fruit on long peduncles (pedicels) to be geotropic responsive. A breeder selecting long, narrow, pendant fruits in a backcross program would also be selecting for low FDF. However, selecting for increased fruit diameter in both pendant and upright-oriented fruit genotypes should result in greater FDF.

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