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Breeding Strawberries for Fruit Firmness[1]

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Additional index words. Fragaria X *ananassa,* fruit texture, fruit puncture force, heritability, fruit breeding

Abstract. **Heritability estimates for fruit firmness of strawberry (*Fragaria* X *ananassa* Duch.) based on the regression of mean offspring performance on average parent performance varied from 0.49 to 0.67 over a 4 year period. Analysis of variance of progeny data showed that general combining ability variance (additive) was much greater than specific combining ability variance. Of 29 parent clones studied 'Holiday', 'Linn', 'WSU 1522' and 'MD-US 3184' had the firmest fruit and on the basis of progeny analysis had the highest general combining ability parental values. Low parental values were obtained for 'Tamella', 'Benton', 'Puget Beauty', 'WSU 1019', 'OR-US 3291' and 'OR-US 3522'.**

Improvement in fruit firmness is a major objective of many strawberry breeding programs. Firm fruited cultivars are more suited to fresh market shipping, show less damage in mechanical harvesting and when processed retain their texture better than cultivars with soft fruit.

Objective evaluations of fruit firmness are routinely used by breeders and are relatively simple (3, 4, 7, 8, 9, 11). However recommended breeding strategies and suggested methods for selecting parents and superior progenies have varied. Hansche et al. (7) obtained moderately high heritability estimates for fruit firmness and suggested that selection based on parental phenotype would result in significant and predictable gains among offspring. On the other hand Spangelo et al. (12) obtained low estimates of heritability and significant nonadditive variance and suggested that progeny testing should be used to determine the superior families from which subsequent selection could be made. This study was undertaken to clarify the nature of inheritance of fruit firmness in strawberry by estimating heritability over a 4-year period and determining the importance of general (additive) and specific combining abilities.

Materials and Methods

Fruit firmness was measured as puncture force, the force (g) recorded on a Chatillon push-pull gauge (Model 516-500) necessary for a 5 mm diameter flat rod to penetrate into a ripe fruit. Each year puncture force determinations were based on an evaluation of three fruits at each of four harvest dates. Phenotypic assessment of 12 cultivars and 13 advanced selections (all subsequently referred to as clones) was made over a 4-year period. Puncture force determinations were also made on the fruit of more than 2,400 seedlings from 119 progenies involving 29 parent clones. In each year 21 seedlings from each progeny were planted in three blocks of seven seedlings each. Each seedling plot consisted of a matted row 1 m in length. Within each block two plots of each parent clone were planted. Due to plant death and sterility not every seedling could be evaluated.

In each of 4 years heritability estimates (h^2) were determined from the linear regression of mean offspring performance on average performance of their parents (5). Progeny puncture force evaluations were analyzed each year by a procedure suggested by Gilbert (6) for data from many crosses not made in a systematic manner. The procedure estimates general combining ability (GCA) and specific combining ability (SCA) variances and determines their significance. The procedure also determines GCA parental values as a guide in breeding.

Results

Phenotypic assessment of puncture force for parent clones showed large differences between clones with 'Holiday', 'Linn', 'WSU 1522', and 'MD-US 3184' having very high values (Table 1). The clones with the softest fruit were 'Olympus', 'Rainier', 'Puget Beauty', 'WSU 1019' and three OR-US selections '3291', '3522' and '3551'.

Large differences were observed between parent clones in GCA parental values. High parental values were found for 'Holiday', 'Linn', 'MD-US 3184' and 'WSU 1522' while low values were obtained for 'Tamella', 'Benton', 'Puget Beauty', 'WSU 1019', 'OR-US 3291' and 'OR-US 3522' (Table 1). Over the 4-year period GCA parental values and phenotypic assessments of puncture force were correlated ($r = 0.75$, $n = 43$).

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Table 1. Phenotypic and genotypic puncture force assessments for 29 strawberry clones determined from 1973 to 1976.

Parent clone	Phenotypic assessment of puncture force[z] (g)	Genotypic assessment	
		No. seedlings[y]	General combining ability parental values
	1973		
MD-US 3184	371 ab	83(4)	197±5
OR-US 3580	386 a	41(2)	192±7
Shuksan	349 abcd	140(7)	186±5
Redchief	346 bcd	82(4)	183±5
WSU 1224	340 bcd	104(5)	178±5
Olympus	315 de	165(8)	174±4
Rainier	332 cd	123(6)	173±5
OR-US 3664	371 ab	80(4)	171±6
Hood	360 abc	41(2)	171±8
WSU 1019	326 cd	84(4)	151±5
OR-US 3291	284 e	40(2)	150±7
OR-US 3522	312 de	42(2)	141±6
	1974		
Holiday	499 a	104(5)	258±5
Redchief	–	41(2)	218±7
Shuksan	459 b	81(4)	209±5
Olympus	394 e	241(12)	205±3
Rainer	386 ef	39(2)	204±8
OR-US 3551	363 f	40(2)	201±7
WSU 1019	383 ef	105(5)	186±5
Totem	493 bc	182(9)	183±4
Northwest	–	40(2)	178±7
Puget Beauty	408 de	60(3)	173±6
Hood	428 cd	122(6)	172±4
	1975		
WSU 1522	443 a	77(4)	212±6
Shuksan	393 b	19(1)	194±10
Hood	408 b	62(3)	191±6
OR-US 3965	–	96(5)	191±6
WSU 1532	402 b	102(5)	190±5
MD-US 3184	468 a	42(2)	188±7
Olympus	344 d	96(5)	185±5
Totem	395 b	102(6)	182±4
WSU 1570	398 b	79(4)	181±6
WSU 1574	383 bc	42(2)	178±8
Puget Beauty	401 b	41(2)	174±7
WSU 1575	362 cd	40(2)	170±8
Benton	–	52(3)	158±6
	1976		
Linn	477 a	163(8)	230±4
WSU 1525	–	62(3)	219±7
OR-US 3580	422 bc	42(2)	214±8
Hood	402 bcd	84(4)	209±7
Shuksan	434 b	201(10)	205±4
WSU 1522	–	41(2)	204±9
Totem	414 bcd	225(11)	203±4
OR-US 3522	–	59(3)	199±8
WSU 1532	–	41(2)	197±7
Merton Dawn	393 cd	201(10)	196±4
Olympus	390 cd	239(12)	190±3
WSU 1520	–	61(3)	188±7
Tamella	389 cd	237(12)	176±3
Puget Beauty	380 d	206(10)	175±3

[z] Mean separation within years by Duncan's multiple range test, 5% level.

[y] Number of families in brackets.

Table 3. Heritability estimates for puncture force.

Year	Number of families	Heritability (h^2) with standard error
1973	24	.596 ± .10
1974	20	.671 ± .01
1975	18	.550 ± .16
1976	34	.487 ± .10

Analysis of variance of progeny data showed that in each year GCA was highly significant and that SCA was always much lower, although significant in 1974 and 1976 (Table 2). Heritability estimates based on offspring/parent regression analysis varied from 0.487 in 1976 to 0.671 in 1974 (Table 3).

Discussion

This study confirms the outstanding fruit firmness of 'Holiday' (NY 1144), 'Linn', 'MD-US 3184', and 'WSU 1522', the intermediate firmness of 'Shuksan', 'Totem' and 'Hood' and the relatively soft fruit of 'Puget Beauty', 'Olympus', 'Rainier', 'Tamella', 'Merton Dawn' and 'WSU 1019' (2, 3, 8, 10, 11).

Estimates of heritability in the present study agree very closely with the estimate of 0.46 by Hansche et al. (7) who also objectively measured fruit firmness and used offspring/parent regression to estimate heritability. Because of the relatively high heritability estimates for puncture force and the large proportion of additive (GCA) variance observed parental phenotype can be used to predict offspring puncture force. Such very firm clones as 'Holiday', 'Linn', 'WSU 1522' and 'MD-US 3184' produced a high proportion of seedlings with outstanding firmness. The source of firmness in 'Holiday' and 'WSU 1522' was their common parent 'NY 844' and in 'Linn' was its parent 'MD-US 3184'. The heritability estimates in the present study differed considerably from the very low estimates (0.10-0.26) of Spangelo et al. (12). Their use of subjective estimates of fruit firmness, of different statistical procedures for estimating heritability and of different parental material may explain the poor agreement.

Many of the clones evaluated in this study have been evaluated for ease of capping (calyx removal) (1). A negative phenotypic correlation appears to exist between fruit firmness and ease of capping. The easiest to cap clones, 'Puget Beauty', 'OR-US 3522', 'WSU 1019' and 'Olympus' all had soft fruit while many of the most difficult to cap clones, 'Holiday', 'WSU 1522' and 'MD-US 3184', had very firm fruit in the present study. There were some exceptions to this relationship; clones with soft fruit such as 'Rainier', and 'OR-US 3551' were difficult to cap. Among the clones studied none had the desirable combination of easy capping and firm fruit.

Significant progress has been made by strawberry breeders in developing new cultivars with outstanding fruit firmness. Improvement has been rapid and this is primarily due to the large additive genetic variance and high heritability associated with fruit firmness. This study confirms the conclusion of Hansche et al. (7) that parent selection based on phenotype will lead to a rapid improvement of fruit firmness in seedling populations.

Table 2. Analyses of variance for puncture force showing the significance of general (GCA) and specific (SCA) combining ability.

	1973			1974			1975			1976		
Source of variation	df	Mean square	F value	df	Mean square	F value	df	Mean square	F value	df	Mean square	F value
Additive parental effects (GCA)	14	15.844	7.808**	12	45.349	20.853**	13	10.175	5.682**	13	27.504	14.143**
Interactions (SCA)	14	2.397	1.182	15	11.058	5.085**	9	1.774	0.991	32	3.399	1.748**
Error (within families)	565	2.029		540	2.175		432	1.791		886	1.945	

**Significant, P = 1%.

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Effects of Big Vein Resistance and Temperature on Disease Incidence and Percentage of Plants Harvested of Crisphead Lettuce[1]

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Additional index words. Lactuca sativa, Olpidium brassicae

Abstract. **In 5 spring trials, the percentage of lettuce plants (*Lactuca sativa* L.) showing big vein symptoms was consistently low for the resistant line 72-136 and consistently high for the susceptible 'Great Lakes 65.' Results were less consistent for the moderately resistant 'Merit' and for 'Calmar.' During periods of low temperatures a lower percentage of big vein infected plants than healthy plants was harvested. Results were variable at high temperatures but, in general, differences were less.**

Big vein is a disease of lettuce that is most common in the western United States. The disease is now ascribed to an unknown big vein agent (BVA) once thought to be a virus (1, 2, 4, 5). Westerlund et al. (4) have shown that air temperature is the primary climatic factor affecting the incidence of big vein. The disease is most severe during periods of cold weather. Soil type is a factor affecting the activity of *Olpidium brassicae* (Wor.) Dang, the vector of BVA. The organism, a root-infecting fungus, is most active in big vein prone soils, which are heavy textured and hold water for long periods (5).

There are 2 distinct symptoms of big vein in crisphead lettuce: 1) the vein banding or vein clearing effect on either side of the vascular bundles, and 2) crinkling and stiffening of the frame leaves around the head, giving the plant an upright bushy appearance. The latter symptom is believed to be an expression of failure of the inner frame leaves to curve inward in the process of head formation, thus delaying maturity and leading to reduced head size at the time of harvest.

Researchers and growers have disagreed over the economic importance of big vein. The disagreement centers around the phenomenon of delayed maturity. Studies with 'Great Lakes' lettuce in the Salinas Valley and in Arizona showed that greater proportions of lettuce plants showing no symptoms of big vein were harvested than of plants with big vein symptoms (3, 6). However, it is not unusual to find fields of lettuce with high percentages of the plants showing big vein symptoms that nevertheless produce high yields on the first cutting.

Cultivar use may have some influence on the effects of big vein upon lettuce yield. During the 1950's and early 1960's, the 'Great Lakes' group of cultivars comprised the major portion of the western U.S. lettuce land. These cultivars were smaller and more susceptible to big vein than 'Calmar', which replaced them in the California coastal valleys. 'Calmar' is vigorous and slightly resistant to big vein and is, therefore, able to produce more marketable heads under severe big vein stress. The big vein resistant 'Merit' offers greater protection but is an unsatisfactory cultivar in other ways. The development of cultivars with greater degrees of resistance would provide still greater protection from big vein.

At the U.S. Agricultural Research Station, Salinas, California, we have developed breeding lines with big vein resistance. In these lines fewer plants show symptoms than do susceptible materials. We investigated the effect of big vein on resistant and susceptible lettuce, its role in delaying maturity and reducing yield, and the difference in these effects as influenced by temperature.

Materials and Methods

In 1976, 2 trials were planted on January 5 and February 23, for early and late spring harvest, respectively. In 1977, three trials of the same materials were planted on January 13, January 31 and March 23 for early, mid and late spring harvest, respectively.

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