this develop proliferated tissue characteristic of callus in fruits that survive.

Fruit tissues in the outer cortex at bloom time are particularly susceptible to frost injury. Although injury was slight, the outer cortex separated from the hypodermis and subsequent healing was accomplished by the formation of callus tissue which engulfed the wound area. As the healing of these wounds progressed, a rough epidermal surface developed with pronounced lenticels.

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Comparison of Factors Influencing Fruit Size in Large-Fruited and Small-Fruited Clones of Strawberry[1]

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Abstract. The relative decline in fruit size from primary to secondary to tertiary positions on the inflorescence of large-fruited clones was much greater than for small-fruited clones. Large-fruited clones produced fruit with more achenes and larger achenes than did small-fruited clones. Fruit weight was positively correlated with total achenes per fruit, developed achenes per fruit, mean weight of total and developed achenes, and fruit weight per developed achene. These results lead to the conclusion that fruit size differences among strawberry clones are due to the combined effects of developed achene number, developed achene size, differential activity of achenes in producing growth hormones and differential sensitivity of receptacular tissue in responding to growth hormones.

Fruit size is one of the most important characters for evaluating or developing strawberry cultivars. Large fruit size is especially important in merchandising fresh-market strawberries, and is also a significant factor in reducing harvest costs. Most strawberry breeding programs have large fruit size as one of their major objectives.

Considerable variability exists in fruit size among strawberry cultivars. Large size differences also exist within individual inflorescences of a cultivar, depending on fruit position on the inflorescence (1, 3, 5, 10, 11). There is a marked decrease in fruit size with each inferior blossom position on the inflorescence. Sherman and Janick (10) reported that the relative decline in size of fruits from the primary berry to inferior flower positions on the inflorescence was approximately the same in all cultivars. Janick and Marshall (6) found that the rate of decrease in fruit size in later pickings was similar for the 9 cultivars studied. Valleau (11), however, presented data which showed that fruit size of inferior positions, calculated as percent of primary size, ranged from 63 to 90% for secondary berries, 35 to 55% for tertiaries, and 25 to 40% for quaternary berries in 3 genetic clones. Valleau's data also showed that the greatest percent decrease in berry size occurred in the clone with the largest primary berry and the least percent decrease in inferior positions occurred in the clone with smallest primary fruit size. Darrow (1) found that the relative size decrease of fruits in inferior inflorescence positions varied greatly among genetic clones and was related to type of inflorescence branching.

Fruit size, number of achenes, and position of the fruit on the inflorescence are closely related within a cultivar (3, 5, 7, 11). Both fruit size and achene number show a decrease with lower flower positions (5, 11). That fruit enlargement in the strawberry is dependent upon hormones produced by the achenes was clearly shown by Nitsch (9).

This study investigates the factors influencing fruit size in large-fruited and small-fruited clones of strawberry.

Materials and Methods

The two largest-fruited ('NC 2840', 'Md-US 3082') and the two smallest-fruited ('Blakemore', 'Md-US 3365') genetic clones in a test planting of 57 cultivars and selections were selected for study. Each clone was replicated 5 times in a randomized block design.

During fruiting in 1969, 5 fruits from each of 3 flower positions (primary, secondary, tertiary) were collected at random from each replication of each clone as they matured. The fruits were labeled, placed in plastic bags, and stored in a freezer.

In October, each fruit was weighed and volume measured as amount of water displacement. Individual fruits were macerated in a laboratory food blender. Achenes that floated in water were considered undeveloped and achenes that sank were considered developed (8). Both types of achenes were collected, dried, counted, and weighed.

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Results

The mean fruit weight of the small-fruited clones, 'Blakemore' and 'Md-US 3365', was only 43% as great as the mean weights of the large-fruited clones, 'NC 2840' and 'Md-US 3082' (Table 1). However, the difference in fruit size of the 2 groups was significant only at the primary and secondary fruit positions. The tertiary fruit size did not differ significantly among clones. The fruit volumes closely paralleled the fruit weights. Both fruit weight and fruit volume decreased significantly in all clones with inferior fruit position. A greater percent decrease, however, occurred in the large-fruited selections. These selections showed an average secondary fruit weight of 44 percent, and average tertiary weight of 14 per cent of the primary weight, compared with 56 per cent and 30 per cent of primary weight for the secondaries and tertiaries, respectively, of the small-fruited clones.

'Md-US 3082' contained more total and developed achenes per fruit than the other clones at all fruit positions, with the greatest difference being at the primary position (Table 1). 'NC 2840' had more total and developed achenes at the primary position than did 'Blakemore' and 'Md-US 3365', but not at the secondary and tertiary positions. In fact, 'NC 2840' had the fewest achenes at the tertiary position. All selections showed decreasing total and developed achenes with inferior flower positions.

The total achene weight and the developed achene weight per fruit closely parallel the data on achene number. 'Md-US 3082' had the greatest weight of both total and developed achenes. 'NC 2840', while not differing in mean achene number, had a greater mean total and developed achene weight than the small-fruited clones. This was a result of 'NC 2840' having larger achenes (Table 2). Both total and developed achene weight decreased with inferior fruit positions.

The total and developed achenes of 'Md-US 3082' averaged larger than achenes of other clones (Table 2). This was obvious in comparing achene size of primary berries. The other large-fruited clone, 'NC 2840', produced achenes significantly larger than either of the small-fruited clones. The achenes of all clones tended to be smaller with inferior flower positions, and the main effect of fruit position on size of both total achenes and developed achenes was significant.

Since enlargement of the strawberry fruit is due to the sum of the effects of individual achenes (9) the average contribution of each achene to fruit size can be calculated as mean fruit weight per achene (Table 2). Each achene of 'NC 2840' was responsible for a greater amount of fruit weight than any of the other clones. Each achene of the other large-fruited clone, 'Md-US 3082', produced more fruit weight than did individual achenes of the small-fruited clones, 'Blakemore' and 'Md-US 3365'. With progressively inferior fruit position there was a significant decrease in fruit weight per total achene. However, the effect of fruit position on weight per developed achene was not significant, although there appeared to be a trend to less individual achene effect with inferior fruit position.

The ratio of unit fruit weight to unit seed weight is shown in Table 2. A much greater fruit weight can be attributed to each unit of seed weight in 'NC 2840' than in the other clones. Although 'Md-US 3082' had larger achenes, greater total achene weight per berry, and

Table 1. Effect of fruit position on fruit weight and volume, total and developed achenes per fruit, and achene weight per fruit of 4 strawberry clones.

Clone	Fruit position							
	Primary^x	Secondary^x	Tertiary^x	Mean^y	Primary^x	Secondary^x	Tertiary^x	Mean^y
	Fruit weight				Fruit volume			
		g				cc		
NC 2840	21.6a	9.5b	2.8ef	11.3a	22.8b	11.2c	2.9fg	12.3b
Md-US 3082	22.2a	9.8b	3.0ef	11.7a	24.8a	12.5c	3.3fg	13.5a
Blakemore	9.4b	5.1d	2.4f	5.6b	10.7c	5.4e	2.2g	6.1c
Md-US 3365	6.9c	3.9e	2.3f	4.4c	8.5d	4.3ef	2.2g	5.0d
Mean^z	15.0a	7.1b	2.6c		16.7a	8.4b	2.7c	
	Total achenes per fruit				Developed achenes per fruit			
		No.				No.		
NC 2840	338b	163de	45g	182b	282b	118e	37h	146b
Md-US 3082	407a	182d	136e	242a	355a	157d	102ef	205a
Blakemore	272c	171d	70g	171b	218c	158d	61gh	146b
Md-US 3365	242c	155de	103f	167b	209c	127e	79fg	138b
Mean^z	315a	168b	89c		266a	140b	70c	
	Total achene weight per fruit				Developed achene weight per fruit			
		mg				mg		
NC 2840	158b	68e	17h	81b	136b	59d	15g	70b
Md-US 3082	237a	87d	48f	124a	220a	80c	42e	114a
Blakemore	103c	66e	22gh	64c	87c	62d	21fg	57c
Md-US 3365	98cd	56ef	33g	62c	92c	52de	29f	58c
Mean^z	149a	69b	30c		134a	63b	27c	

^{x}Means of clone x position. Values within each group followed by the same letter are not statistically different at the 5% level of significance (Duncan's multiple range test).
^{y}Main effect of clone. Means within the column followed by the same letter are not statistically different at the 5% level of significance.
^{z}Main effect of position. Means within the row followed by the same letter are not statistically different at the 5% level of significance.

greater fruit weight per achene than the 2 small-fruited clones, it did not differ from 'Blakemore' in achene unit weight effect on fruit size.

Fruit weight was positively correlated with total achenes per fruit, developed achenes per fruit, mean weight of total achenes, mean developed achene weight, total achene weight per fruit, developed achene weight per fruit, fruit weight per total achene, and fruit weight per developed achene (Table 3). The number of total achenes and developed achenes per fruit were positively correlated with average weight of total and developed achenes, and total weight of both total and developed achenes. A significant negative correlation occurred between total achenes per fruit and milligrams of fruit per milligram developed achene weight.

Significant positive correlations occurred between average weight of both total and developed achenes and fruit weight per total and developed achene. Total achene weight per fruit was negatively correlated with milligrams of fruit weight per milligram of total achene weight. Weight of developed achenes per fruit was negatively correlated with milligrams of fruit weight per

Table 2. Effect of fruit position on mean weight of achenes, fruit weight per achene, and unit fruit weight per unit achene weight of 4 strawberry clones.

Clone	Fruit position							
	Primary^x	Secondary^x	Tertiary^x	Mean^y	Primary^x	Secondary^x	Tertiary^x	Mean^y
	Mean total achene weight				Mean developed achene weight			
	mg				mg			
NC 2840	0.47b	0.42c	0.38cde	0.42b	0.49b	0.50b	0.43c	0.47b
Md-US 3082	0.58a	0.47b	0.35def	0.47a	0.62a	0.51b	0.41cd	0.51a
Blakemore	0.38cde	0.39cd	0.31f	0.36c	0.40cd	0.39cd	0.34e	0.38c
Md-US 3365	0.40cd	0.36def	0.33ef	0.36c	0.44c	0.41cd	0.37de	0.41c
Mean^z	0.46a	0.41b	0.34c		0.49a	0.45b	0.39c	
	Fruit weight per total achene				Fruit weight per developed achene			
	mg				mg			
NC 2840	65ab	58ab	70a	64a	79ab	84a	89a	84a
Md-US 3082	55b	55b	23c	44b	63b	64b	30c	52b
Blakemore	35c	30c	34c	33c	43c	33c	39c	38c
Md-US 3365	29c	25c	22c	25c	33c	31c	29c	31c
Mean^z	46a	42ab	37b		55a	53a	47a	
	Mg fruit wt per mg total achenes				Mg fruit wt per mg developed achenes			
	mg				mg			
NC 2840	138bc	141b	180a	153a	161b	166b	204a	177a
Md-US 3082	94de	115cd	64f	91b	102cde	124c	73e	100b
Blakemore	91de	78ef	111d	93b	109cde	83de	117cd	103b
Md-US 3365	71ef	69ef	68ef	69c	76e	75e	78e	76c
Mean^z	99a	101a	106a		112a	112a	118a	

^{x}Means of clone x position. Values within each group followed by the same letter are not statistically different at the 5% level of significance (Duncan's multiple range test).
^{y}Main effect of clone. Means within the column followed by the same letter are not statistically different at the 5% level of significance.
^{z}Main effect of position. Means within the row followed by the same letter are not statistically different at the 5% level of significance.

Table 3. Simple correlation coefficients between strawberry fruit size, achene weight, and achene number.

Measurement^x	Measurement^x										
	2	3	4	5	6	7	8	9	10	11	12
1	.99**	.90**	.88**	.81**	.75**	.93**	.90**	.43**	.34*	.17	.21
2		.89**	.87**	.87**	.80**	.93**	.91**	.51**	.44**	.20	.21
3			.99**	.74**	.63**	.97**	.95**	.16	.09	−.25	−.46**
4				.76**	.61**	.97**	.96**	.15	.04	−.28	−.21
5					.87**	.85**	.87**	.55**	.44**	.18	.16
6						.66**	.76**	.55**	.56**	.47**	.26
7							.99**	.27	.19	−.63**	−.01
8								.26	.02	−.67**	−.53**
9									.95**	.91**	.89**
10										.92**	.94**
11											.98**

^{x}*Measurements*
1 = Mean fruit weight
2 = Mean fruit volume
3 = Total achenes per fruit
4 = Developed achenes per fruit
5 = Mean achene weight (total)
6 = Mean achene weight (developed)
7 = Total achene weight per fruit
8 = Developed achene weight per fruit
9 = Fruit weight per total achene
10 = Fruit weight per developed achene
11 = Unit fruit weight per unit total achene weight
12 = Unit fruit weight per unit developed achene weight
*Significant at 5% level.
**Significant at 1% level.

milligram of both total and developed achenes. The amount of fruit weight that could be attributed to each total and developed achene had high positive correlations with milligrams of fruit per milligram of both total and developed achene weight.

No consistent effect of fruit position on the ratio of developed to total achenes within the clones occurred and the main effect of fruit position on percent of total achenes that were developed was not significant (Table 4). Very little difference existed among the various genetic clones in percent of developed achenes.

Table 4. Percentage of developed achenes at various fruit positions on 4 strawberry clones.

Clone	Fruit position			Mean[y]
	Primary[x]	Secondary[x]	Tertiary[x]	
	%	%	%	%
NC 2840........	83abc	71d	82bc	79b
Md-US 3082....	87ab	86ab	75cd	83ab
Blakemore......	80bcd	93a	87ab	87a
Md-US 3365....	86ab	83abc	78bcd	82ab
Mean[z]......	84a	83a	80a	

[x]Means of clone x position. Values within each group followed by the same letter are not statistically different at the 5% level of significance (Duncan's multiple range test).

[y]Main effect of clone. Means within the column followed by the same letter are not statistically different at the 5% level of significance.

[z]Main effect of position. Means within the row followed by the same letter are not statistically different at the 5% level of significance.

Discussion

The decrease in fruit size with each inferior fruit position "down" the inflorescence is well documented in the strawberry (1, 3, 5, 10, 11). Some reports (5, 6, 10) indicate that the relative decline in fruit size with each inferior position may be similar in all cultivars. The results obtained in this study, however, show that the percent fruit size decline varies markedly among genetic clones. The relative decline in fruit size of the 2 large-fruited clones was much greater than for the 2 small-fruited clones. This agrees with the findings of Valleau (11). In this study, clones with similar primary size tended to decline in fruit size with inferior fruit positions in about the same percentage.

The close relationship between achene number and fruit size found in this study agrees with previous reports (3, 5, 7, 11). The high positive correlation coefficients of .90 and .88 between fruit weight and total and developed achene number, respectively, indicate that fruit weight is closely tied to achene number. The data indicate, however, that achene size may also be important. The 2 large-fruited clones had larger achenes than the small-fruited clones. Achenes at each inferior position within a clone were smaller than achenes from fruit in superior positions on the inflorescence. High correlation coefficients between average achene weight and fruit size were obtained.

Darrow (2) found a wide range in achene size of strawberry cultivars. While he did not report fruit size, he did note that achenes of 'Blakemore' were smaller than those of the larger-fruited 'Marshall'. Also, small-fruited diploid species had smaller achenes than the larger-fruited octaploid species.

Individual achenes from the large-fruited clones, 'NC 2840' and 'Md-US 3082', were responsible for relatively more fruit weight than achenes of the 2 small-fruited clones. Also, achenes from superior positions on the inflorescence tended to produce greater fruit weight. That this effect is not due entirely to average achene size is shown by comparative data of 'NC 2840' and 'Md-US 3082'. Although the achenes of 'NC 2840' were significantly smaller than those of 'Md-US 3082', each 'NC 2840' achene was responsible for significantly greater fruit weight. Thus, the achenes of some genetic clones may produce a greater amount of growth hormone or the receptacular tissue may be more responsive to a given amount of hormone.

Since the ratio of developed to undeveloped achenes was nearly the same in all clones and fruit positions, the correlation between fruit size and total and developed achenes was similar. However, only the developed achenes are active in influencing fruit size (9). Under conditions of poor achene set, each developed achene may promote relatively more fruit growth than under conditions of good achene set (7). Maximum fruit size and best symmetry, however, occurs when a high percent of achenes are fertilized and develop (7). Although no significant differences were found in this study, others have reported that a lower percent of achenes develop at each inferior fruit position, presumably as a result of increasing pistil sterility (5, 11).

Differences in fruit size among strawberry clones and among various positions on an inflorescence within a clone appear to be due to combined effects of developed achene number, developed achene size, and either differential activity of achenes in producing growth hormones or differential sensitivity of receptacular tissue in responding to growth hormones. The latter response may be expressed as extended duration of cell division (4) or increased enlargement of individual cells (3). Since hormone studies were not conducted, we can only speculate on the role of growth hormones in influencing fruit size differences. Studies of hormone production of developing achenes and response of the developing receptable to hormones are needed to clarify the effect of hormones on fruit size differences among and within cultivars.

Differenes in fruit size at different positions within an inflorescence are primarily due to differences in achene number since little difference exists among positions when relative fruit size per achene is compared. Variations in fruit size among genetic clones, however, may occur as a result of any or all of the 3 determining factors: achene number, achene size, and achene activity. The relative importance of each of these may vary with genetic clones. Thus, 'Md-US 3082' produces large fruit as a result of large achene number and large achene size. The fruit of 'NC 2840' appears to be large because of a greater growth-promoting activity of individual achenes. Cultivars with even larger fruit might be developed by combining genotypes with high achene number, large achene size, and high achene growth-promoting activity.

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Population Density and Growth Rate of Head Lettuce (*Lactuca sativa* L.) in an Arid Climate with Sprinkler Irrigation[1]

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Abstract. Using sprinkler irrigation for the entire season allowed a change in bed conformity for head lettuce. Growing 6 rows on an 82-inch bed introduced a maturity variable, with the 2 outside rows having larger heads or heads with greater numbers of leaves.

On a flat soil surface with plants on square spacings of 10 × 10, 12 × 12, 14 × 14, 16 × 16, and 24 × 24 inches, growth was slowed but total yields increased as density increased. Using 'Climax' and the present system of packaging 24 or 30 heads per carton, the 14 × 14-inch spacing produced the greatest number of cartons per acre. The greater yields at the 10 × 10-inch spacing (45 tons per acre) were small heads that would be acceptable only for shredding.

Recent investigations of sprinkler irrigation for vegetable culture in Imperial Valley, California, have led to its extensive use for germination and seedling emergence (4). The primary advantages of sprinkler irrigation are the prevention of surface salt accumulation on seed beds (5, 6, 8) and maintenance of better soil aggregation (7). The higher emergence rates achieved by sprinkling have enhanced the feasibility of precision seed placement, which facilitates the use of mechanical thinners (2, 4). Because furrows were not needed to deliver water in the sprinkler area, other bed conformities could be examined. Plants could be grown on a wide 82-inch bed (7). Flat surface plantings could be grown in grid systems which isolated each plant within a specific area for growth (3, 9). On such grid plantings carrots grown in a 2-inch grid produced double the conventional yield, and those in a 4-inch grid matured 25 days sooner than the 2-inch spacings (3). Sugar beets on a sprinkled flat grid system had maximum sucrose production at 12-inch intervals (9). Head lettuce produced in Florida showed that close spacings of 10 × 14 and 12 × 14 inches produced many small heads while wider spacings produced larger heads that matured earlier (1).

This report presents observations of a commercial planting of head lettuce in wide 82-inch beds using sprinkler irrigation and a later experiment of flat-culture sprinkled head lettuce at spacings of 10 × 10, 12 × 12, 14 × 14, 16 × 16, and 24 × 24 inches. The study was made to identify the total yield and head size produced at each population density, and to note physiologic differences with plant density.

Materials and Methods

The 40-acre commercial trial on wide 82-inch beds was planted on 4 separate dates, each area comprising 10 acres. "Forty-niner" was used in the first planting (September 29, 1967), and "Climax" in all others (October 6, 13, and 18, 1967). A precision planter (Hansen, John Deere) placed seed approximately 1.5 inches apart in 6 rows spaced 12 inches apart on an 82-inch bed. Phosphorus was applied preplant at 269 pounds per acre. Total N applied was 200 pounds per acre including one application of $CaNO_3$ as preplant, and 2 later applications through the sprinklers. To keep the soil surface moist, irrigation was applied daily until emergence, then applications were for 12-hour periods at approximately 2-week intervals. The nozzles (size 3/32) were placed on 30 × 40-foot spacings and operated at 40 psi.

Plants were thinned by hand to approximately 12-inch intervals. For sampling, plants were cut at ground level and the aerial portion was placed in a sealed plastic bag to prevent moisture loss. Ten plants were taken from each of the 6 rows in each of 2 locations in each planting. Plants were then weighed and the leaves counted as an indication of maturity. (10).

The field experiment on plant density was conducted in a permanent sprinkler-irrigated field with 20 × 20-foot plots replicated 3 times. 'Climax' seeds were spaced at 2-inch intervals in a water soluble plastic seed tape, which was placed on a flat soil surface that had been rototilled to incorporate 200 pounds of P per acre. The seed tapes were placed at intervals of 10, 12, 14, 16, and 24 inches, and after 21 days the plants were thinned to produce symmetrical grids. NH_4NO_3 was applied through sprinklers to supply a total of 110 pounds of N per acre: 50 at planting (October 20, 1969), 20 after thinning (on November 11), and 40 prior to heading (on January 6, 1970). Plants were sampled in alternate rows periodically, with each whole plant placed in a plastic bag after washing the tap root. Whole plants were weighed and the leaves counted. When heads were formed, the head weight and number of leaves in the head were determined.

The initial irrigation lasted 20 hours. Daily 2-hour applications followed during the first week, to prevent the seedlings from drying out on the soil surface. Applications were then on a weekly schedule. The water applied was equivalent to the amount of water evaporating

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