STALK DIAMETER AS A FACTOR IN FRUIT SIZE

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Among those factors determining the size to which a fruit will grow, the diameter of its stalk or pedicel should evidently be considered, for through this structure must pass all the material of which the fruit is composed. In the author's cultures of *Cucurbita pepo* there are genetic races differing greatly in fruit size, ranging from types derived from the Connecticut field pumpkin (Line CF) with a fruit diameter of about 300 mm. to small, roundish gourds of about 50 mm. (Line SRC). The purpose of the present study is to determine whether there is any relation in these races between the stalk diameter and the size of their fruits.

In small races like SRC the stalks are about 5 mm. in diameter at maturity and in large ones like CF, about 20 mm. The ratio of fruit diameter to stalk diameter is therefore not very greatly different in the two types. The ratio of fruit *volume* to cross sectional area of stalk, however, is obviously far greater in the larger types than in the small, the former having about 14 times as much fruit volume per unit cross section of stalk as the latter. On the basis of these figures, stalk diameter would therefore seem to have little limiting effect on the attainment of fruit size. It is obvious that the flow of material through the stalk must be very much faster in the large races. It should be remembered, however, that it takes much longer for the fruit of the large race to reach full size than for that of the small, so that more time is available to deliver material to the growing fruit.

In an attempt to gain more information on this problem, two methods of attack were undertaken: a study of the relative growth rate of stalk to fruit in large-fruited and small-fruited races, and a study of growth rate and fruit size in developing fruits of both types where the cross-sectional area of the stalk was experimentally reduced.

GROWTH STUDIES

Daily caliper measurements were made of stalk diameter and of ovary length and width in more than 50 normally growing ovaries belonging to eight races of *C. pepo* ranging in mature fruit size from a volume of about 60 cc. to one of 10,000 cc. Readings were made to tenths of a millimeter on stalk diameter and small ovary dimensions, and to the nearest millimeter on larger ones. They were begun with the smallest ovary primordia that could be measured without injury, usually about five to eight days before the opening of the flower, and were continued until growth ceased. This study was made on field-grown plants at the peak of their development, during the last two weeks of July and the first two of August.

The relation between fruit size and the rate and duration of growth in this material has previously been described by the author (1945). From the beginning of development until about three to ten days after flowering (depending on the race) growth is exponential, and the logarithms of the dimensions, when plotted against time, fall along an essentially straight line. Growth rate then falls off gradually until it ceases altogether. *Rate*

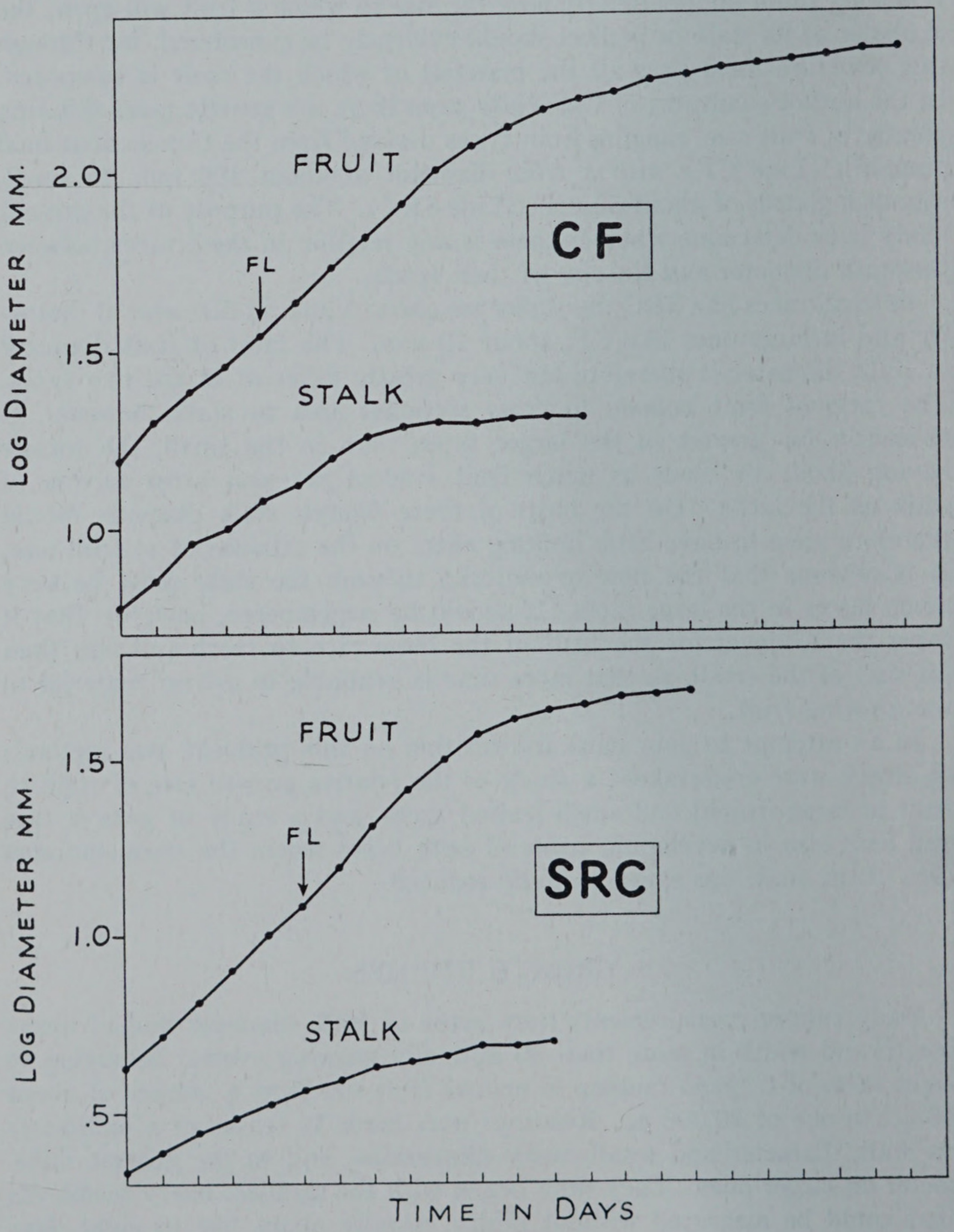

FIG. 1. Growth curves, in days, of the logarithms of diameter of stalk and of fruit in a typical example of a large-fruited line (CF) and of a small-fruited line (SRC). FL marks the day when the flower opened.

of growth during the exponential period is approximately the same in large-fruited and in small-fruited types. The *duration* of both phases of growth, however, is considerably larger in the large-fruited races, and it is to this that the size differences in the mature fruit are due. Typical growth curves for a fruit of a large and of a small race are shown in FIG. 1.

Growth of the stalk in diameter follows the same program as of the ovary, with an early exponential phase succeeded by a gradual diminution until growth ceases. Stalk growth differs in two respects, however, from that of fruit: its exponential growth rate is lower, and its growth ceases much earlier, when the fruit is only one-fourth of its final size or less. These relations are also shown in FIG. 1. As a result, the differential in size between fruit diameter and stalk diameter, which at the beginning is not very great, continually increases.

Between the large and the small races there are differences in these growth relationships. In the large ones the exponential growth rate of the stalk is considerably higher than in the small. In a typical growth curve of the line CF, for example, it is about 16% per day, but in line SRC only 10%. These rates compare with about 22% for daily fruit growth in both. The relative growth of stalk to fruit is thus related to the typical fruit size at maturity. The relative-growth constant of stalk diameter to fruit diameter was determined in the usual manner for six races and is shown in TABLE 1, together with the typical mature fruit volume of each race.

TABLE 1

Line	Volume of typical mature fruit in cc	Constant of relative growth (k) of stalk diameter to fruit diameter
CF	10,000	.69
P	2,500	.62
AC	680	.65
HG	290	.63
TA	70	.48
SRC	60	.48

At two points on the growth curve there is a relationship between stalk growth and fruit growth in all races which may have morphogenetic significance. One is at the time of flowering. The proportional logarithmic difference between stalk and fruit diameter steadily increases and in both large and small types, when this difference reaches about 5 or 6 logarithmic units, flowering occurs. In other words, the flower opens when the diameter of the young fruit has reached about three to four times that of the stalk. This is quite independent of the absolute size of either. Since the stalk grows faster in large types than in small, it takes longer in them for this absolute differential to be reached, and thus both ovary and stalk are considerably larger at flowering than they are in small types.

The fact is also evident, whatever its significance, that the end of exponential fruit growth coincides with the end of growth in stalk diameter. Thus all the post-exponential growth of the fruit, during which its volume increases four-fold or more, takes place after the stalk has reached its full size.

EXPERIMENTS

To determine whether the diameter of the stalk actually influences the size to which the fruit will grow, this diameter was experimentally reduced in growing fruits of both large and small types.

In one series this was done by half severing the young stalk by cutting a deep nick out of its side as far as the center of the pith, so that only half of the normal area of the stalk was available for transport of material from plant to fruit. The operation was performed on the day of flowering, or near it. About half the operated flowers stopped growing in a day or two and died, apparently because the cut was too deep, too much sap was lost, or infection set in. In ten fruits, belonging to four lines and differing widely in their normal fruit size, however, active growth continued. The cut surfaces healed well and although considerable scar tissue was formed, vascular connection across the gap was not restored. Daily caliper measurements of ovary width were made on these fruits. In every case where growth continued after the operation it proceeded at the normal rate, and growth curves for these fruits are not different in any notable way from those for intact ones.

Stalk diameter was also reduced by artifically constricting the stalk early in development and thus preventing its growth. Attempts to do this by embedding the stalk in plaster of Paris failed, for the plaster was soon cracked by stalk growth. Constriction was successfully accomplished by winding coarse, soft cotton string around the stalk, firmly but not too tightly, for a length of from several millimeters to a centimeter. In some of the stalks thus bound the string was reinforced by a layer of plaster. Binding was usually done on the day of flowering or shortly thereafter. Young ovaries from six lines were thus constricted.

Many of these failed to grow and died in a few days. Twenty-three continued to develop, however, and width measurements on them were made daily. Growth curves of such fruits, from both large and small races, were essentially normal as to rate and total final size.

After growth had ceased, the stalks were freed and examined. In every case it was found that growth had either been greatly reduced or had not taken place at all after binding. The tissues of the stalk were poorly developed and the vessels were much narrower than in normal stalks. Diameter of the stalk above and below the constriction was a little affected.

DISCUSSION

Experimental evidence shows that a stalk very much smaller in cross section than normal, either because of the removal of part of it or the prevention of its growth, will nevertheless conduct material from plant to fruit as rapidly and to as large a final amount as a stalk of normal diameter. This confirms the results of some other workers, notably Werner (1931). He found after cutting off all the roots of a maize plant except one small prop root and thus reducing the amount of vascular connection between soil and plant to about one thousandth of its normal cross-sectional area, that the plant grew almost as well as the controls and the amount of transpiration was essentially normal.

Other evidence has shown that the volume of the transpiration stream conducted through a young stem is not related to the amount of xylem which is developed there; in other words that "functional stimulus" of a tissue does not result in its greater development. This is what we should expect from a study of anatomical evidence. In *Osmunda*, for example, the cross sectional area of the xylem of a leaf trace as it leaves the stele is only about ⅛ that which it attains in the rachis above, but this small bundle conducts all the water that the large one does. The large and complex vascular system of a cycad leaf, also, is connected with the vascular axis of the stem by only two small bundles. Evidently in such cases, including the ones here described, the conducting capacity of a structure is considerably higher than it is normally called upon to display, and increased demands upon it do not increase its size.

The close relationship between stalk growth and fruit growth in the material here described, however, and especially the difference in growth patterns between large-fruited and small-fruited types suggests that there may be a correlative growth influence between stalk and fruit which is not related merely to transport of material. The fact that stalk diameter grows more slowly than fruit diameter necessarily results in an increasing tension, so to speak, between the two which might be expected ultimately to affect fruit growth. The further fact that when this growth differential reaches a certain absolute size, flowering takes place in both large and small types, suggests that this differential is in some way related to the attainment of sexual maturity. As the difference grows still greater, another change — the cessation of exponential growth in the fruit — occurs, again suggesting that there is a correlative influence of stalk on fruit. What the physical basis of this correlation may be is unknown. It would be interesting to study the auxin relationships between stalk tissue and ovary tissue in these plants.

We may conclude that there is a definite relation between the relative-growth pattern of the stalk and the fruit in *Cucurbita pepo*, but that the size of the fruit does not depend directly on the cross-sectional area of its stalk.

SUMMARY

Diameters of developing fruits and fruit stalks were measured daily in races of *Cucurbita pepo* differing widely in mature fruit size.

Growth of the stalk is slower and ceases earlier in small-fruited races than in large-fruited ones.

In both, flowering occurs when the ratio of ovary diameter to stalk diameter has reached a specific size.

Artificial reduction of stalk diameter by cutting away part of it or by constricting it had no appreciable effect on fruit growth.

Size of fruit does not depend on cross-sectional area of the stalk but there seems to be a correlation between the growth pattern of the stalk and that of the fruit, which is related to fruit size.

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