# THE POLLINATION OF TOMATOES [1]

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SUMMARY

1 A good correlation was found between size of the fruit and the number of seeds. But the greater the number of seeds, the lower is the fruit weight per seed.

2 Pollination with mixtures of pollen with an inert powder gives larger and earlier fruits the more pollen there is in the mixture. *Lycopersicum peruvianum* pollen has a similar effect on fruit growth as tomato pollen, although no seeds are formed.

3 The more frequent the pollination the more seeds per fruit.

4 The more seeds already developing on a plant, the smaller is the fruit weight which newly developing seeds will contribute to the fruits containing them.

5 Good pollination can be accomplished by the use of an electric vibrator which accelerates the harvest and gives a higher percentage of the better grades of fruit.

6 Auxin sprays will increase the number of fruits containing a small number of seeds, but which are still of a good size. The stronger the auxin, the greater will be the increase.

7 If light conditions are poor, extra light will aid the production of normal flowers, and the use of a vibrator will ensure a better fruit set.

8 If conditions for tomato growing are poor, the greater is the emphasis to be laid on good pollination.

CONTENTS



## 1. INTRODUCTION

In most crops in which the yield consists of the fruits, pollination of the flowers is of great importance. This is especially true of tomatoes, in which pollination is essential for obtaining fruit set and normal fruit growth i.e. development of fruits with seeds.

The wild strains from which the cultivated tomatoes originated were cross-pollinated. In these strains the style extends far beyond the anthers. By selection, probably unconsciously, of plants that were self-fertile, most of our

1) Received for publication September 25, 1956.

recent tomato varieties have styles which do not extend beyond the anther cone, and this facilitates self-fertilization.

Studies were made of the effect of pollination on fruit set, normal fruit growth, earliness of yield and the size of the fruit. The action of auxins on fruit growth was also a subject of study.

## 2. Experimental

### 2.1. *Fruit weight per seed*

*Introduction* In order to study the effect of the number of seeds per fruit on the weight of the fruit, it was found important to introduce the factor of fruit weight per seed. This is the weight of the fruit or fruits, divided by the number of seeds which they contain. It can be determined for one fruit or the whole fruit yield on a given day, or even for a whole crop.

*Number of seeds per fruit and fruit weight per seed* Fruit weight and the number of seeds in the fruits were determined several times. In addition to the number of seeds in a fruit there are many other factors that may have an effect on the fruit weight. To find any correlation between fruit weight and seed number it is necessary to take a large number of fruits. Fruits were classi-

Table 1 Relation between number of seeds and fruit weight per seed.

| Variety or cross | Seed number per fruit | Number of fruits | Mean number of seeds per fruit | Mean fruit weight in g | Mean fruit weight per seed in g |
|---|---|---|---|---|---|
| Yellow Globe .. | 1– 20 | 26 | 9 | 70 | 7.5 |
| | 21– 40 | 25 | 31 | 103 | 3.3 |
| | 41– 60 | 22 | 50 | 129 | 2.6 |
| | 61–100 | 28 | 81 | 151 | 1.9 |
| | 101–140 | 21 | 117 | 165 | 1.4 |
| | 141–200 | 23 | 171 | 166 | 1.0 |
| | 200–440 | 19 | 280 | 248 | 0.9 |
| Yellow Globe × Ailsa Craig .... | 1– 20 | 25 | 10 | 78 | 7.8 |
| | 21– 40 | 23 | 30 | 114 | 3.8 |
| | 41– 80 | 25 | 56 | 127 | 2.3 |
| | 81–140 | 19 | 111 | 148 | 1.3 |
| | 141–300 | 24 | 187 | 183 | 1.0 |
| (Yellow Globe × Ailsa Craig) × Ailsa Craig .... | 1– 20 | 11 | 12 | 37 | 2.99 |
| | 21– 40 | 12 | 32 | 51 | 1.61 |
| | 41– 60 | 33 | 50 | 62 | 1.22 |
| | 61– 80 | 33 | 72 | 69 | 0.96 |
| | 81–100 | 18 | 92 | 69 | 0.76 |
| | 101–120 | 29 | 110 | 83 | 0.76 |
| | 121–140 | 33 | 130 | 73 | 0.56 |
| | 141–160 | 24 | 152 | 77 | 0.50 |
| | 161–180 | 20 | 170 | 80 | 0.47 |
| | 181–200 | 19 | 188 | 88 | 0.47 |
| | 201–260 | 24 | 226 | 104 | 0.46 |
| | 261–340 | 15 | 322 | 146 | 0.45 |
| John Baer ..... | 1– 20 | 11 | 9 | 66 | 7.17 |
| | 21– 40 | 6 | 32 | 89 | 2.78 |
| | 41– 80 | 8 | 57 | 112 | 1.96 |
| | 81–160 | 6 | 139 | 146 | 1.05 |
| | 161–240 | 8 | 216 | 163 | 0.75 |
| | 241–480 | 9 | 335 | 218 | 0.65 |

fied by the number of seeds they contained. Table 1 shows four examples. Correlations between seed number and fruit weight were calculated as 0.96, 0.97, 0.96 and 0.99 respectively for the four examples.

The table shows that:

a) it is the larger fruits that have the greater number of seeds per fruit,
b) the more seeds are contained in a fruit, the smaller is the fruit weight per seed.

The importance of good fertilization is clearly shown by the following.
Let the number of seeds $= x$ $\quad \log x = x'$
The fruit weight per seed $= y$ $\quad \log y = y'$,
then the fruit weight is $xy$, $\log xy = \log x + \log y = x' + y'$.
If these points are plotted on a graph it will be seen that they are on a straight line $y' = mx' + q$.
Using the examples in table 1 and two other examples in tables 2 and 4, the following equations are found:

| | |
|---|---|
| Yellow Globe (table 1): | $y' = -0.643\,x' + 149$ |
| Yellow Globe x Ailsa Craig (table 1): | $y' = -0.722\,x' + 162$ |
| (Yellow Globe x Ailsa Craig) x Ailsa Craig (table 1): | $y' = -0.649\,x' + 117$ |
| John Baer (table 1): | $y' = -0.688\,x' + 146$ |
| John Baer (table 2): | $y' = -0.768\,x' + 161$ |
| Tuckqueen (table 4): | $y' = -0.693\,x' + 168$ |

There are no reliable differences between these equations; $y' = -0.69\,x' + 151$ is true of every example.

## 2.2. *Pollination, number of seeds per fruit, and fruit weight per seed*

A high positive correlation was found between the number of seeds per fruit and the weight of the fruit. Hence the next step is to obtain more seeds per fruit. The number of seeds is approximately equal to the number of fertilized egg cells, and to fertilize an egg cell a living pollen grain has to germinate on the style. It is only indirectly possible for the number of fertilized egg cells to be affected by applying more pollen to the style, this usually resulting in a greater number of fertilized egg cells and consequently a greater number of seeds. Experiments were performed in order to prove this assumption.

It is first necessary to emasculate the flowers used, and afterwards to study the effect on the number of seeds and fruit weight of pollination with different amounts of pollen grains.

It is not easy to pollinate with a known number of pollen grains and for this reason pollination mixtures were used of different estimated amounts of pollen with inactive Lycopodium powder. By dipping the styles of the emasculated flowers in different mixtures, different degrees of pollination were obtained.

This method was applied to a male sterile type of the John Baer variety. Mixtures of 100 %, 10 %, 1 % and 0.1 % pollen were used but only one mixture on a given plant. Eighty to a hundred fruits were picked per treatment. The results and the values expressed as percentages of the values for 100 % pollen are shown in table 2.

Table 2 Effect of pollination with 100 %, 10 %, 1 % and 0.1 % pollen.

| | | Absolute values | | | | Percentages | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Percentage of pollen in the medium ........ | 100 | 10 | 1 | 0.1 | 100 | 10 | 1 | 0.1 |
| 2 | Mean number of seeds per fruit .......... | 153 | 72 | 12 | 7 | 100 | 47 | 8 | 5 |
| 3 | Mean fruit weight in g | 136 | 108 | 72 | 63 | 100 | 79 | 53 | 46 |
| 4 | Mean fruit weight per seed in g .......... | 0.89 | 1.50 | 6.24 | 9.22 | 100 | 167 | 689 | 1022 |
| 5 | 100 seed weight in mg | 389 | 440 | 483 | 500 | 100 | 113 | 124 | 129 |
| 6 | Seed weight per fruit in mg ............ | 595 | 317 | 56 | 34 | 100 | 53 | 9.4 | 5.7 |

This table shows that whereas the pollination has a range of 1–1000, the range for the number of seeds is only 1–20, and for the fruit weight only 1–2. Consequently a fruit which is twice as heavy as another has twenty times as many seeds, and to reach this number pollination has to be a thousand times heavier.

Thus where more pollen grains are applied to the style heavier pollination results in more seeds, but also in relatively fewer seeds in proportion to the heavier pollination. A larger amount of seed results in a larger fruit, but this is again relatively smaller in proportion to the increase of seeds. The relation between the last two factors is shown in row 4 of the table, where it can be clearly seen that where there are fewer seeds each seed has a greater effect on fruit weight. Row 5 shows larger seeds when the number per fruit is less, although the differences are slight, and this results in the relatively small differences between rows 2 and 6.

Since earliness is so important in a tomato crop, table 3 shows the results on earliness of the different pollinations.

Table 3 Fruit yield in grams, up to the date specified, resulting from the use of different pollination mediums.

| Date \ % pollen in the medium | 100 | 10 | 1 | 0.1 |
|---|---|---|---|---|
| July 14 .............. | 348 | 160 | | |
| July 17 .............. | 493 | 530 | | |
| August 1 ............. | 1048 | 880 | 200 | 150 |
| August 8 ............. | 1718 | 1540 | 710 | 393 |

Conclusions : a heavier pollination results in larger, earlier fruits with more seeds. The heavier the fruits the more difficult it is to increase their size.

The Tuckqueen variety was used in a second experiment to show the effect of pollination with different amounts of pollen. All clusters except the second and third were pinched-off. Each of 5 treatments (control, Lycopodium powder, 100 %, 10 % or 1 % pollen) was given to each of the two clusters, each flower being given one treatment. In this way a maximum of 10 fruits was able to develop on each plant, resulting in abnormally large fruits.

Except for treatment 1, the treatments listed in column 1 of table 4 were applied to emasculated flowers. The same method was used as before, but on this occasion *Lycopersicum peruvianum* pollen was used in addition to tomato pollen.

Table 4 Effect of different pollinations with pollen of tomato and *Lycopersicum peruvianum*.

| Treatment | Number of fruits | Growing period in days | Number of seeds per fruit | Fruit weight in g | Fruit weight per seed in g |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 1 Control . . . . . . . . | 83 | 71.8 | 171 | 244 | 1.42 |
| 2 Lycopodium powder . | 95 | 76.3 | – | 48 | – |
| 3 100 % tomato pollen . | 46 | 71.0 | 75 | 183 | 2.45 |
| 4 100 % peruvianum pollen . . . . . . . . . | 50 | 69.0 | – | 169 | – |
| 5 10 % tomato pollen . . | 50 | 74.4 | 12 | 86 | 6.94 |
| 6 10 % peruvianum pollen . . . . . . . . . | 51 | 72.3 | – | 76 | – |
| 7 1 % tomato pollen . . | 50 | 73.6 | 3 | 67 | 25.06 |
| 8 1 % peruvianum pollen | 47 | 73.1 | – | 73 | – |

At least 46 fruits were harvested per treatment (column 2), which is enough to give a reliable mean. Each fruit was harvested separately, so that the time of development from flower to ripe fruit was known (column 3). The number of seeds, weight of fruits and fruit weight per seed were determined (columns 4, 5 and 6).

Unlike the experiment described above, all the various treatments were applied to the same plant, so that the different flowers of one plant were pollinated with different amounts of pollen, as may be expected to be the case in practice.

The heavier the pollination, the shorter is the mean development time (column 3 : cf. treatments 3, 5, 7, 2 and also 4, 6, 8 and 2).

It seems that pollination with pollen of *Lycopersicum peruvianum* results in faster fruit growth than with tomato pollen (cf. treatments 3 and 4, 5 and 6, 7 and 8). In the case of the peruvianum pollen, which has smaller grains, it is possible that a larger number may fall on the style, resulting in a larger number of fertilizations and hence a larger number of growing embryos. After 2 to 4 weeks, however, the embryos abort (Yeager and Purington, 1946). The result is a normal growing fruit, but without seeds.

Two other suggestions are that *Lycopersicum peruvianum* pollen contains more auxin, or that the fruit growth is faster because the aborted embryos no longer require nutriment after 4 weeks.

The number of seeds per fruit (column 4) decreases with decreasing pollination, but not as fast as the amount of pollen used. The numbers of seeds in the control fruits are much greater than in the case of the 100 % pollen treatment. To explain this, it must be remembered that the controls were the only unemasculated flowers, and that these flowers could therefore be pollinated many times, resulting in more seeds (cf. the next experiment on repeated pollination).

The mean fruit weight (column 5) decreases as less pollen is used.

There is, however, a great increase in the fruit weight per seed (column 6) as less pollen is used.

The earliness in yield is shown in table 5, in this case as the percentage of the fruit weight harvester within a certain number of days.

Table 5 Percentage of the yield within a certain number of days after pollination.

| Treatment \ Number of days | 0–66 | 67–72 | 73–78 | 79–84 | 85–90 | 91–96 |
|---|---|---|---|---|---|---|
| 1 Control . . . . . . . . . . | 15 | 68 | 93 | 100 | | |
| 2 Lycopodium powder . . | 1 | 44 | 68 | 94 | 97 | 100 |
| 3 100 % tomato pollen . . . | 24 | 66 | 94 | 100 | | |
| 4 100 % peruvianum pollen | 29 | 81 | 99 | 100 | | |
| 5 10 % tomato pollen . . . | 18 | 57 | 88 | 95 | 99 | 100 |
| 6 10 % peruvianum pollen . | 31 | 71 | 88 | 94 | 96 | 100 |
| 7 1 % tomato pollen . . . . | 8 | 51 | 89 | 97 | 100 | |
| 8 1 % peruvianum pollen . | 20 | 55 | 87 | 97 | 98 | 100 |

The importance of pollination is clearly shown by comparing treatments 1 and 2, the importance of heavy pollination by comparing treatments 3, 5 and 7, while a comparison of treatments 3 and 4, 5 and 6, 7 and 8 would seem to imply that *Lycopersicum peruvianum* pollen works faster than does tomato pollen. These results agree with those found in table 4.

In this case also it must be concluded that a heavier pollination gives an earlier and higher yield of larger fruits.

From these two experiments it may be further concluded that to obtain the maximum effect from a small amount of pollen, it is advisable to mix with a large amount of powder as a carrier.

*Repeated pollination* The effect of repeated pollination at daily intervals can be seen from table 6. The more frequent the pollination, the greater is the number of seeds per fruit and the lower the fruit weight per seed.

Table 6 Effect of repeated pollination on the number of seeds per fruit and the fruit weight per seed.

| | Number of fruits | Number of seeds per fruit | Fruit weight per seed in g |
|---|---|---|---|
| Pollinated twice . . . . . . . . . . | 11 | 98 | 1.06 |
| Pollinated 3 times . . . . . . . . | 31 | 118 | 1.03 |
| Pollinated 4 times . . . . . . . . | 26 | 130 | 0.89 |

## 2.3. *Number of seeds present on the plant and fruit weight per seed*

The connection between number of seeds per fruit and fruit weight per seed was shown (p. 39). In addition to the number of seeds, there are other factors affecting the fruit weight. One of these will be discussed here.

In experiments a and b performed during the summer in the greenhouse, harvesting took place fortnightly. Table 7 shows the mean number of seeds per fruit, fruit weight and fruit weight per seed for the total yield. This again

Table 7 Connection between the mean number of seeds per fruit, mean fruit weight and mean fruit weight per seed in the Tuckqueen variety.

| Experiment | a | b |
|---|---|---|
| Mean number of seeds per fruit ............ | 88 | 140 |
| Mean fruit weight in grams ................ | 64 | 91 |
| Mean fruit weight per seed in grams ........ | 0.72 | 0.65 |

shows that a larger number of seeds per fruit is connected with a higher mean fruit yield, but with a lower fruit weight per seed.

Since a tomato yield is distributed over a long period the time factor will be included. Since harvesting was carried out fortnightly, the fruit weight per seed can be determined for each fortnightly period. In fig. 1 a and b this is shown by the dashed lines. The fruit weight per seed decreases with time, is found to have a minimum in graph b, and again increases considerably after this minimum.

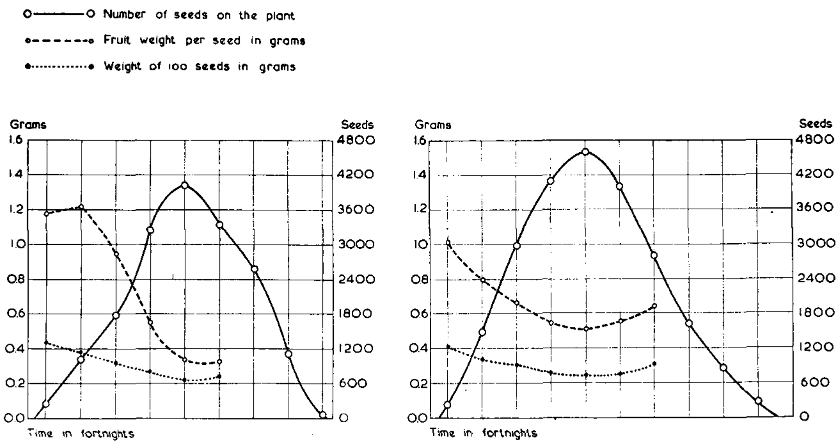


FIG. 1a AND b NUMBER OF SEEDS PER PLANT IN CONNECTION WITH FRUIT WEIGHT PER SEED AND 100 SEED WEIGHT, DURING THE GROWING PERIOD.

To explain this it was assumed that an important factor might be the number of seeds on the plant at the moment new seeds begin to grow. If the mean time for development of the fruits is considered to be about 8 weeks, it is possible to calculate the number of seeds on the plant every fortnight (shown in fig. 1 a and b by the full line). A striking negative correlation was found between the fruit weight per seed and the number of seeds on the plant when seed growth began, viz. –0.96 and –0.98 for experiments a and b respectively. Hence the greater the number of seeds on a plant the less will be the fruit weight per seed produced by the newly fertilized seeds. The maximum of the curves indicating the number of seeds on the plant coincides with the time when the seeds which have just started to grow will give the smallest fruit weight. This is the result of competition between the seeds.

The weights of 100 seeds are shown by the dotted lines. They also have the same tendency as the fruit weight per seed, but are much less pronounced.

It must be borne in mind that during the growth of the plants there is also an increase in the number of leaves, although this is relatively less than the number of seeds.

### *2.4. Number of seeds per fruit and per grade*

The fruit weight per seed was studied in connection with the number of seeds on the plant in relation to time. We will now discuss the number of seeds per grade related to time (experiment b). The different grades are shown in table 8.

Table 8 Grades used.

| | |
|---|---|
| Grade B larger than .......... | 69 mm |
| „ A .................. | 57–69 mm |
| „ C .................. | 47–57 mm |
| „ CC .................. | 41–47 mm |
| „ chats smaller than ...... | 41 mm |

Table 9 shows the mean number of seeds per grade, the mean fruit weight, and the mean fruit weight per seed. In this case also more seeds are found in heavier fruits. Contrary to expectation, however, the fruit weight per seed of the fruits having the largest number of seeds is not the lowest. To find the explanation of this it is necessary to include the time factor.

Table 9 Relation between number of seeds, fruit weight and fruit weight per seed for different grades.

| Grade | B | A | C | CC | Chats |
|---|---|---|---|---|---|
| Mean number of seeds per fruit .... | 220 | 170 | 121 | 56 | 14 |
| Mean fruit weight in g ........... | 175 | 106 | 69 | 41 | 17 |
| Mean fruit weight per seed in g .... | 0.79 | 0.62 | 0.57 | 0.74 | 1.23 |

Fig. 2 shows the number of seeds per grade per fortnight. The amount of seeds per grade increases at the beginning, reaches a maximum after about 8 weeks and then decreases. This means that in order to obtain the same grade in the first eight weeks, an increasing number of seeds are required and thereafter a decreasing number. This is in complete agreement with the results in fig. 1 b, in which the fruit weight per seed also decreased to a minimum during the first eight weeks, and then tended to increase again. But this does not explain why the fruit weight per seed for grade B is higher than expected. To understand this it is necessary to study the relative composition of the yield in grades during the harvest weeks. Fig. 3 shows that the largest grade (B) is found more in the first harvesting periods, the smaller grades, especially C and CC, more in the later periods. Hence most B graded fruits are formed in the period when each seed produces a relatively high fruit weight.

The number of seeds per fruit did not show much variation with time, and consequently as can be seen in fig. 3, the number of smaller fruits will increase beyond that of the higher grades, because the same number of seeds in a fruit will give a lower fruit weight.

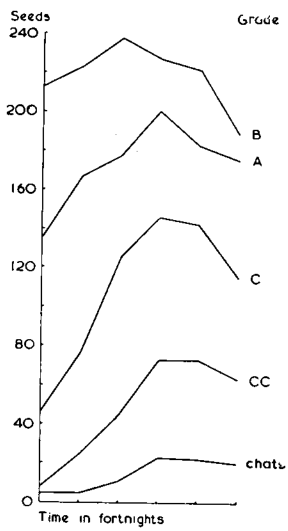


FIG. 2 NUMBER OF SEEDS PER GRADE WITH TIME.

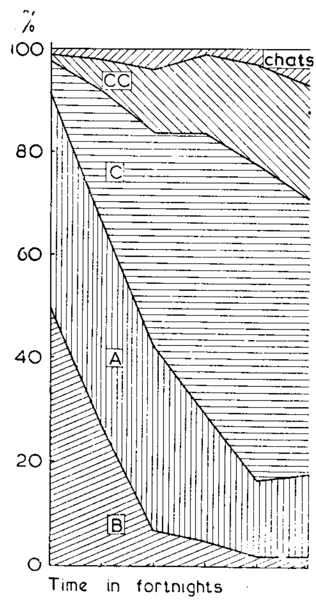


FIG. 3 CHANGE IN GRADE PERCENTAGES WITH TIME.

## 2.5. *The artificial bee*

*Introduction* The great importance of a heavy pollination has been emphasized. We will now discuss how such a pollination may be effected.

The former practice in the Netherlands was to shake the plants in order to obtain a good pollination.

After the second world war a small machine was introduced. (COTTRELL-DORMER, 1945; WELLENSIEK, 1948). This contains an interruptor with a button by means of which a needle can be shaken. The anther cone of the flower is held in the eye of the needle, and by vibrating it the flower is vigorously shaken and consequently pollinated. This buzzer is called the artificial bee, as it imitates the action of a bumble bee.

A study was made of the effect of the use of this machine, especially in order to discover its effect on earliness of yield. The effect of the use of the artificial bee (vibration = + v) was measured by expressing the yield when using the artificial bee as percentages of the yield when it was not used (–v).

In 1953 another kind of pollinator was introduced from the U.S.A., viz. a vibrating iron rod by means of which a whole cluster can be vibrated simultaneously (KERR and KRIBS, 1955). It operates much faster than the artificial bee. It is not yet known for certain if it is as effective, but preliminary tests have shown that it probably is.

*Introductory pollination test with the artificial bee* Flowers of the Tuckqueen variety were pollinated with the artificial bee (+v), and other flowers from the same plants were used as controls (–v). Treatments were given on July 12 and 21 and harvesting took place weekly. The results are shown in tabel 10. Column 3 shows that the fruits grown from vibrated flowers needed

4–7 days less for development than the controls, i.e. the use of the artificial bee gives an earlier yield.

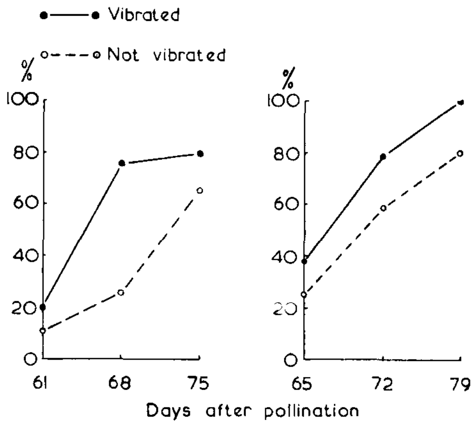


FIG. 4 PERCENTAGES OF FRUITS HARVESTED WITHIN A CERTAIN NUMBER OF DAYS AFTER POLLINATION.

The same result can be seen in fig. 4 which shows the percentage of the yield after different numbers of days for two dates. Fruits from vibrated flowers not only ripen earlier, (table 10, column 3), but are also larger (column 4) and have many more seeds (column 5) with, of course, a heavier total weight (column 7.). The fruit weight per seed is much less after vibrating (column 6). All results are the same as those found for a heavier pollination compared with a lighter pollination (compare p. 38–42). Pollination must have been greatly improved by vibrating the flowers with the artificial bee.

Table 10 Results of pollination test with the artificial bee.

| Observations and dates of treatment | Number of fruits | | Mean growing period in days | | Mean fruit weight | | Mean number of seeds per fruit | | Mean fruit weight per seed in g | | Mean seed weight per fruit in mg | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | |
| Treatment | 12/7 | 21/7 | 12/7 | 21/7 | 12/7 | 21/7 | 12/7 | 21/7 | 12/7 | 21/7 | 12/7 | 21/7 |
| —v ........... | 23 | 17 | 77.4 | 74.9 | 94 | 104 | 101 | 131 | 0.93 | 0.80 | 309 | 431 |
| +v ........... | 28 | 18 | 70.8 | 70.5 | 118 | 150 | 181 | 220 | 0.65 | 0.68 | 566 | 707 |
| +v/−v × 100 .. | | | 91.4 | 94.1 | 126 | 144 | 179 | 168 | 70 | 85 | 183 | 164 |

*Fruit yield* The effect of the use of the artificial bee on all flowers of a crop will now be discussed. The plants were stopped after the fifth or sixth cluster.

In order to give a clear idea of the effect of the artificial bee, the effect on total weight and mean fruit weight of treated plants is expressed as percentages of the controls. The controls were not pollinated in any special way. Table 11 shows the results of different experiments. In all cases the mean fruit weight is higher than the controls, and generally the total yield also. The mean fruit yield usually increases more than the yield. This means that the number of fruits produced from the treated plants is usually less than in the controls.

Table 11 Effect of the use of the artificial bee on total yield (+v/−v × 100).

| Experiments in ......... | Heated greenhouses | | | | | Unheated greenhouses | | | |
|---|---|---|---|---|---|---|---|---|---|
| Number of experiment .. | I | II | III | IV | V | VI | VII | VIII | IX |
| a Mean fruit weight ... | 131 | 152 | 196 | 120 | 135 | 109 | 106 | 111 | 125 |
| b Total fruit yield .... | 134 | 129 | 169 | 125 | 113 | 100 | 97 | 114 | 110 |

Since earliness is so important, the earliness of the treated plants as compared to the untreated ones is shown in table 12 where it can be seen that not only are the ultimate mean fruit weight and yield usually higher, but also the yields of the treated plants much earlier; the mean weight of the fruits is always higher.

Table 12 Effect of the artificial bee in relation to time, expressed as +v/−v × 100 and cumulatively determined during successive pickings.

| Experiments in ......... | Heated greenhouses | | | | | Unheated greenhouses | | | |
|---|---|---|---|---|---|---|---|---|---|
| Number of experiment .. | I | II | III | IV | V | VI | VII | VIII | IX |
| a Mean fruit weight ... | 137 | 115 | 127 | 112 | 196 | 112 | 113 | 127 | 115 |
| | 122 | 148 | 164 | 136 | 170 | 118 | 111 | 151 | 144 |
| | 121 | 152 | 119 | 151 | 158 | 116 | 111 | 128 | 128 |
| | 124 | 162 | 150 | 134 | 128 | 112 | 110 | 117 | 122 |
| | 130 | 166 | 188 | 123 | 132 | 113 | 110 | 106 | 120 |
| | 131 | 152 | 200 | 122 | 133 | 114 | 109 | 116 | 121 |
| | | | 204 | 121 | 129 | 117 | 110 | 121 | 127 |
| | | | 200 | 124 | 132 | 114 | 110 | 110 | 124 |
| | | | 196 | 120 | 135 | 109 | 106 | 111 | 125 |
| b Fruit yield .......... | 204 | 400 | 1627 | 126 | 145 | 213 | 125 | 260 | 234 |
| | 164 | 244 | 1074 | 157 | 143 | 126 | 124 | 224 | 233 |
| | 137 | 147 | 415 | 160 | 144 | 116 | 117 | 143 | 147 |
| | 135 | 137 | 288 | 135 | 98 | 94 | 112 | 131 | 128 |
| | 135 | 122 | 212 | 125 | 91 | 93 | 98 | 118 | 121 |
| | 134 | 129 | 191 | 122 | 96 | 101 | 91 | 113 | 120 |
| | | | 178 | 118 | 101 | 107 | 90 | 100 | 103 |
| | | | 169 | 116 | 104 | 100 | 92 | 114 | 110 |
| | | | 169 | 125 | 113 | 100 | 97 | 114 | 110 |

For the purpose of studying the total weight and mean fruit weight of each cluster, table 13 shows the figures for a hothouse and a cold-house experiment.

Table 13 Effect of the use of the artificial bee per cluster (+v/−v × 100).

| Cluster | Heated greenhouse | | Unheated greenhouse | |
|---|---|---|---|---|
| | Mean fruit weight | Total yield | Mean fruit weight | Total yield |
| 1 | 174 | 150 | 135 | 154 |
| 2 | 170 | 185 | 106 | 100 |
| 3 | 149 | 99 | 116 | 89 |
| 4 | 142 | 114 | 116 | 99 |
| 5 | 165 | 154 | 93 | 133 |
| Whole plant ....... | 154 | 130 | 111 | 114 |

It can be seen that in nearly every cluster the mean fruit weight is higher than in the controls, and usually the total yield per cluster also. Furthermore, the effect is greatest in the hothouse experiment, and greater in the first clusters than in the later ones. In the third cluster there is no effect, or a slightly depressing one on total yield. This is the time at which most seeds are found on the plants and the fruit weight per seed is lowest (cf. p. 43).

Table 14 shows that what has just been stated regarding the total yield with time, is practically true of each separate cluster as well. On each cluster the treatment with the artificial bee results in an earlier yield (cluster 5 in the coldhouse experiment being the only exception).

Table 14 Effect of the artificial bee on earliness of yield per cluster (+v/−v × 100).

| Cluster \ Period until | Heated greenhouse | | | | Unheated greenhouse | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 11/6 | 24/6 | 8/7 | 19/7 | 23/7 | 6/8 | 20/8 | 10/9 | 8/10 |
| 1 | 245 | 623 | 117 | 35 | 190 | 173 | 98 | 267 | 353 |
| 2 | 428 | 151 | 141 | 45 | 825 | 98 | 128 | 37 | 149 |
| 3 | 296 | 127 | 51 | 41 | — | 135 | 82 | 44 | 252 |
| 4 | 651 | 189 | 108 | 41 | — | 183 | 104 | 43 | 281 |
| 5 | — | 118 | 175 | 124 | — | — | 87 | 74 | 193 |
| Whole plant .......... | 253 | 153 | 102 | 69 | 199 | 122 | 97 | 55 | 230 |

It was shown (see p. 38) that more seeds per fruit will usually give a larger fruit. The use of the artificial bee gives a better pollination and consequently larger fruits, and hence more fruits of a better grade. Grading is carried out as explained in table 8, p.

The numbers of fruits of the different grades after using the artificial bee are expressed in table 15 as percentages of the controls. The number of small fruits shows a drastic decrease. The larger grades (especially A) are increased in number. The greatest effect is once again seen in the hothouse experiment. The use of the artificial bee results in a great increase of the better grades.

Table 15 Effect of the use of the artificial bee on the number of fruits of different grades (+v/−v × 100).

| Grade | B | A | C | CC | Chats |
|---|---|---|---|---|---|
| Heated greenhouse ............... | 165 | 208 | 100 | 22 | 42 |
| Unheated greenhouse ............. | 110 | 126 | 109 | 92 | 48 |

*Fruit weight per seed* Fig. 5 shows the fruit weight per seed and the number of seeds per plant for treated and untreated plants in the same way as in fig. 1 a and b. The treated plants have more seeds, but the fruit weight per seed is always lower. The weight per 100 seeds of the treated plants is about 7 % lower than that of the untreated ones.

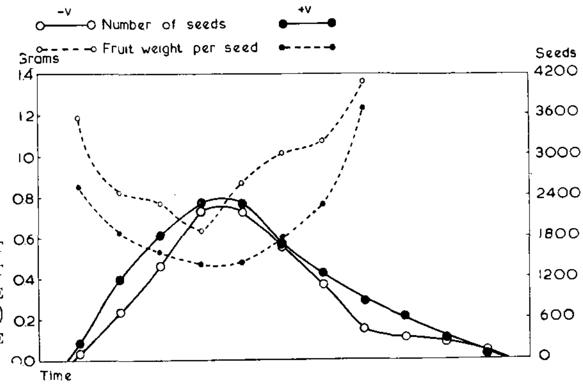


FIG. 5 NUMBER OF SEEDS PER PLANT IN CONNECTION WITH FRUIT WEIGHT PER SEED DURING THE GROWING PERIOD, WITH (+v) OR WITHOUT (—v) THE USE OF THE ARTIFICIAL BEE.

*Conclusions* Pollination with the use of the artificial bee will result in larger fruits and an earlier yield, and usually in a higher total yield also. The seed yield will also be higher.

This is in complete agreement with the effect of a heavier pollination with a pollen mixture having a relatively large number of pollen grains (cf. p. 42).

## 2.6. *Pollination and auxins*

Auxins are often used in tomato growing for the purpose of obtaining better fruit set.

We used strong (++) and weak (+) auxins.

Strong auxins are:

Kresiviet D 30 cc/litre,
Stimocarp 1 tablet/litre,
β-naphtoxyacetic acid 0.25 g/litre,
β-chlorophenoxyacetic acid 0.1 g/litre,
—2 methyl— 4 chlorophenoxysodiumacetate 0.1 g/litre.

Weak auxins are:

No-Seed 2 cc/litre,
Seedless-Set 20 cc/litre,
Shell-Tomato-Set 50 cc/litre,
Betapal 3 cc/litre.

The variety used is Yellow Globe grown in the greenhouse during summer. Water (—) served as a control. The auxins were given to the clusters twice a week in a fine spray, starting at the first anthesis.

Fruits were classified according to the number of seeds they contained. The results are shown in table 16.

This table shows the same results for natural pollination as were found above: the more seeds the larger are the fruits and the smaller is the fruit weight per seed. Most of the fruits (50 %) belong to the class which has more than 61 seeds per fruit. With the use of auxins, however, most fruits belong to the seedless class, but despite this they are still of normal size. The auxins seem to have the same effect on fruit growth as pollination, except, of course,

Table 16 Percentage of fruits, mean fruit weight and fruit weight per seed of different seed classes after using strong (++) or weak (+) auxins, as compared with water (–).

| Seed number per fruit | % of fruits | | | Mean fruit weight in grams | | | Mean fruit weight per seed in grams | | |
|---|---|---|---|---|---|---|---|---|---|
| | – | + | ++ | – | + | ++ | – | + | ++ |
| 0 ..... | 0 | 43 | 75 | 0 | 110 | 129 | – | – | – |
| 1–20 ..... | 22 | 22 | 12 | 67 | 108 | 113 | 5.6 | 13.1 | 15.7 |
| 21–60 ..... | 28 | 15 | 5 | 97 | 108 | 106 | 2.4 | 2.6 | 3.2 |
| 61 ..... | 50 | 20 | 8 | 148 | 134 | 139 | 1.1 | 1.2 | 1.4 |

that no seeds are formed. There is a tendency for fruits having more than 61 seeds to be larger than the others, probably as a result of the large number of seeds. The stronger the auxin the larger is the fruit weight per seed, because part of the function of the seed is taken over by the auxin.

If the auxin reaches the egg cell before pollination can occur, the table shows that pollination is then stopped; the stronger the auxin the smaller is the number of seeds formed.

## 2.7. *Pollination and light*

It is clear that fruit growth cannot take place in the absence of building materials for the fruit. They have to be built up partly by the leaves by means of photosynthesis, and for this reason the effect of light on pollination and fruit growth is important.

An early tomato crop enjoys much less light than the summer crop; moreover the effect of the use of the artificial bee on the earliness of yield was much greater in the hothouses than in the unheated greenhouses (tables 11, 12 and 13), and consequently greater in early spring than in summer. In other words, its effect is greater when the light conditions for the growth of tomatoes are less favourable.

The effect will now be shown of a combination of extra light before, or even after transplanting, and the use of the artificial bee for obtaining good pollination.

In fig. 6 the effect of extra illumination before planting (+L), and use of the artificial bee (+v), are shown separately, and also in combination (+L+v), expressed as percentages of the control (–L–v). The combination of the two effects gives a much earlier yield than either does singly. But the mean fruit weight is largest in treatment –L+v because the fruits from the flowers of the +L+v group have to develop earlier and under less favourable growing conditions than those of the –L+v group (VERKERK, 1955).

Another example is shown in table 17, where extra illumination was provided both before (+L) and after planting (++L). The results are similar to those just discussed, except that it is necessary to emphasize the great effect on earliness of the light after planting.

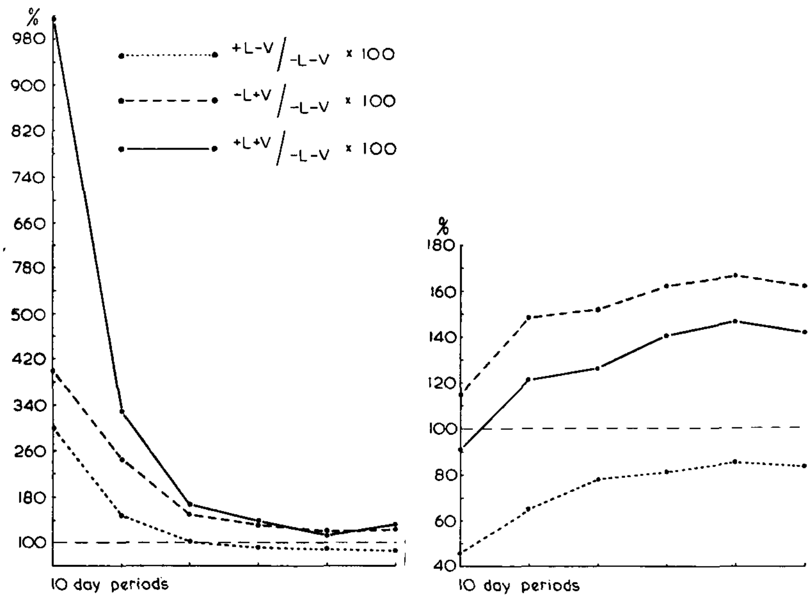


FIG. 6 INFLUENCE OF EXTRA LIGHT BEFORE PLANTING (+L) AND EXTRA POLLINATION WITH THE ARTIFICIAL BEE (+v) ON FRUIT YIELD (LEFT) AND MEAN FRUIT WEIGHT (RIGHT), AS PERCENTAGES OF THE CONTROLS.

Table 17 Effect on fruit yield of extra light, artificial pollination, and both combined.

| Date | 30/5 | 13/6 | 27/6 | 14/7 | 25/7 |
|---|---|---|---|---|---|
| +L—v/—L—v × 100 . . . | 115 | 122 | 99 | 94 | 93 |
| —L+v/—L—v × 100 . . . | 126 | 160 | 125 | 118 | 125 |
| +L+v/—L—v × 100 . . . | 259 | 169 | 122 | 112 | 118 |
| ++L—v/—L—v × 100 . . . | 807 | 216 | 117 | 101 | 89 |
| ++L+v/—L—v × 100 . . . | 1120 | 229 | 124 | 114 | 100 |

## 3. Discussion

### 3.1. *Introduction*

Without auxins growth is impossible. The auxins stimulate the activity of the surrounding tissue and growth is enabled to take place. Food substances, mainly assimilate products such as sugars, are transported to the fast-growing tissues (AUDUS, 1953; CURTIS and CLARK, 1950; TUKEY, 1954). On the other hand, new auxins are probably formed during these periods of rapid growth.

Auxins were found in fast-growing tissues such as unripe fruits, unripe seeds, flower buds, and root tips where high sugar concentrations are generally found. If the tissue containing the auxin is removed the sugar concentration decreases. The exact system is still unknown, but the auxin acts as a powerful system of concentrating sugars and accelerating transport to these tissues (MARRÉ and MURNEEK, 1953), and the result is rapid growth.

If a tomato flower opens and conditions are good, the result will be pollination. Pollen grains germinate on the style and penetrate, growing as far as the egg cells. In the case of the pollen tubes, auxin enters the style and fruit growth begins after fertilization. Without pollination, i.e. without the entry of auxin in the tissue around the egg cells, an abscission layer is formed and the flower drops. If, on the other hand, the young fruit has begun to grow, new auxin will be formed and the growing fruit will remain on the stem until ripe.

MARRÉ *et al.* (1953) found that the same changes occurred in food materials near the egg cells as a result of pollination with viable pollen, as with an application of auxin required to effect fruit growth. But the changes were small when the amount of auxin was relatively low (cf. bad pollination) and when many fast-growing fruits were already developing on the plant.

LUCKWILL (1948) found a good correlation between the fruit growth in the first 6 days and the amount of auxin applied to the style.

The suggestion is that where there is pollination and fertilization auxin enters or is formed in the tissues near the egg cells, and the auxin is responsible for the growth. With auxin alone, i.e. without pollination, the resultant fruit growth is quite comparable to that after pollination, except that no seeds are formed.

On the other hand, it is understandable that for fruit growth the food materials are derived from the $CO_2$-assimilation, so that if assimilation is bad fruit growth cannot be normal.

Thus whereas on the one hand auxin is necessary for starting the mobilization of the food supply, on the other hand assimilation should be adequate for supplying the necessary food material for normal fruit growth.

The rapidity of fruit growth and the size of the ripe fruit will be mainly determined by the amount of auxin and assimilates.

### 3.2. *Auxins and pollination*

*Auxins* In summer assimilates are formed in large quantities, so that the auxin will be one of the limiting factors. In male sterile lines of two tomato varieties, different auxins were sprayed on the clusters twice a week after anthesis of the first flower. A practically normal fruit yield resulted. Thus as far as fruit growth is concerned the auxins are capable of replacing the effect of pollination.

*Pollination* The more seeds formed in a fruit resulting from a heavier pollination, the faster the fruit will grow and the larger it will be (see p. 40–42 and BÖSZÖRMÉNYI, 1952).

This pollination, which is advisable for obtaining a high yield, can be accomplished by using the artificial bee, as described on p. 45–49, but this requires a great deal of labour, and is therefore expensive. A much singler instrument is a vibrating rod used in the U.S.A. for the past twenty years and also in the Netherlands for the past three years. Instead of vibrating every flower separately it vibrates the whole cluster simultaneously. This method is quicker and more effective than the old one of tapping the plants or the supporting strings (KERR and KRIBS, 1955).

*Auxins and pollination* It was shown in table 16 that the use of auxins and pollination followed by fertilization, has the same effect on fruit growth. With the use of strongly-acting auxins (table 16 ++) fertilization is practically suppressed and normal fruit growth was found, but without seeds. The same effect is also found with weakly-acting auxins (+), although in three cases out of four the mean fruit weight is a little lower. In the case of normal fertilization (–), normal sized fruits are only formed when there are a great number of seeds (> 61). With the use of auxins the fruit weight per seed is extremely high, and it increases with decreasing amounts of seeds in the fruit because the auxins replace the action of the growing seeds.

If the fruit grows for some time after fertilization and the egg cells subsequently die, this has no effect on the fruit growth (see p. 41), as is the case after pollination with *Lycopersicum peruvianum* pollen.

### 3.3. *Assimilates*

The effect on fruit growth of the auxin or the developing seed is related to the amount of assimilates available.

Thus it was found that:

a where there are more seeds per fruit, the fruit weight per seed is reduced, so that the same assimilates have to be distributed over more seeds, and this results in less for each seed (p. 43),

b the more seeds already present in a plant, the smaller is the fruit weight which newly-developing seeds will contribute to the fruits containing them (cf. fig. 1),

c when only a relatively small number of fruits develop on a normal sized plant, these fruits will be abnormally large, because every seed is able to obtain a great deal of food (table 4).

MARRÉ *et al.* (1953) mentioned that auxin did not have such a good effect when many large fruits were already developing on the plant. ROBERTS and STRUCKMEYER (1944) found that auxin sprays had less effect when the plants where thin-stemmed as a result of crowding. If the plants have plenty of assimilates at a relatively low temperature, but the fruit set is bad, auxins can help to overcome this (ODLAND and CHAN, 1950; OSBORNE and WENT, 1953; VERKERK, 1955).

Our own experience was that if during summer the first clusters are pollinated very heavily in the greenhouses, the fruits on the upper clusters did not grow so well as long as the first cluster had not been harvested.

MURNEEK (1926) obtained no fruit set, and even dropping of flowers and buds, if many fruits were already developing on his plants. The poorer the conditions governing growth, the more marked was this effect.

If the leaves are removed from a plant fruit set will not take place, even after a good pollination. The leaves have to supply the materials for fruit growth.

The rather low light intensity in winter reduces the plants supply of assimilates (VERKERK, 1955), and even if the flowers open pollination is extremely difficult. In this case auxin sprays will often result in hollow and irregular fruits: parts of the fruit will grow, but the food supply is insufficient to ensure good growth.

With extra illumination during the dull winter days, there is a better chance of obtaining good flowers and great attention shall be paid to pollination

(Verkerk and Wellensiek, 1950). It is shown on p. 50 that the extra light has a very good effect in combination with the use of artificial pollination; otherwise the result is poorer.

The more difficult the assimilation, the greater is the emphasis to be laid on pollination.

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