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Studies on $^{42}K^{+}$, $^{24}Na^{+}$ and $^{32}PO_4^{3-}$ mobility in the strawberry peduncle*

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Both the organic and mineral nutrient substances are transported in plant organisms according to a definite "distribution key" (Górski 1962). The question arises whether the forces causing the directional transport of nutrient substances are inherent in the receptor-organ, which plays the role of the so called "physiological sink", or are controlled by a donor-organ.

The developing fruit is an excellent example of an organ functioning as a "physiological sink". In the previous paper (Antoszewski, Lis 1967) it has been demonstrated that the fruit is a kind of "physiological trap" for various nutrient substances, since these substances when introduced directly into the fruit are not transported down to the peduncle. One may ask what role is played by the vascular system of the peduncle in the formation of such a "physiological trap" as is the fruit. The purpose of the present work was to elucidate this problem.

Particular attention was given to the behaviour of sodium and potassium in the peduncle because of their high mobility in biological systems. Additional investigations were made on the behaviour of phosphorus, since this element occurs both in mineral and in organic form. In this paper the term fruit is used in its pomological sense (Pieniążek 1965).

MATERIALS AND METHOD

The investigations were made on strawberries of the variety 'Talisman' and 'Senga Sengana' (*Fragaria grandiflora* Duch, cv Talisman, Senga Sengana) cultivated the year round in a glasshouse.

The radioactive salts ^{42}KCl, $^{24}NaCl$ and $Na_2H^{32}PO_4$ (Institute of Nuclear Research, Świerk) were used in aqueous solution. The characteristics of the radioactive substances and the processing of the material treated are described in the previous paper (Antoszewski, Lis 1967).

The experiment was carried out in two series. In the first the radioactive substances

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were drop-applied to the peduncle in vivo. Vaseline was used to limit the spread of the drop on the surface.

In some experiments the fruit was immersed in liquid paraffin to prevent transpiration (Fig. 1). Then, before determining the gradient, the paraffin was extracted off the tissue.

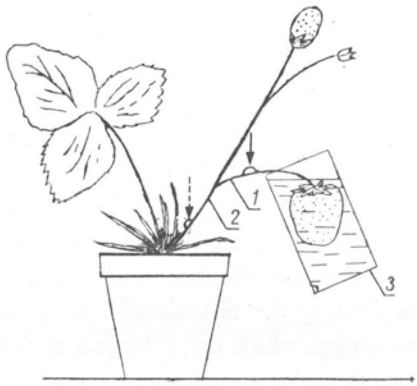

Fig. 1. Mobility of K^+ and Na^+ in the peduncle of fruit with inhibited transpiration. 1) Fruit peduncle, 2) Fruit stem, 3) Liquid paraffin. Arrows mark the sites of application.

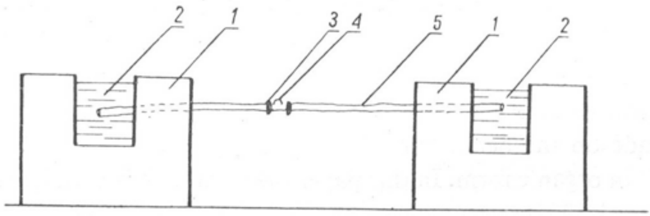

Fig. 2. Mobility of K^+ and PO_4^{3-} in a fruit stem cut from the plant. 1) Plasticine containers, 2) Water, 3) Cotton ring impregnated with vaseline, 4) A drop of radioactive substance, 5) Fruit stem.

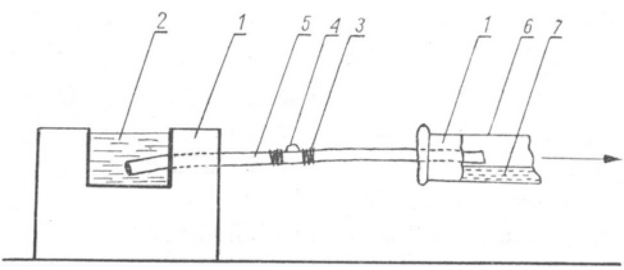

Fig. 3. Mobility of K^+ and PO_4^{3-} in fruit stem with forced flow of water. 6) Glass tube connected to water pump, 7) Outflow obtained due to hypotension (For other notations see Fig. 2).

In the second series of experiments the radioactive substance was applied to a cut off peduncle as shown in Fig. 2.

In some experiments the flow of water in the peduncle was forced by properly applying the water pump, as shown in Fig. 3. After a suitable time period (4 to 6 hrs) the sections of peduncle were cut into 1—3 mm slices, placed on planchets and their activity was determined (Geiger-Müller counter AAH-55).

RESULTS

a) Behaviour of sodium, potassium and phosphate salts applied to the peduncle in vivo

It was observed that $^{42}K^{+}$ and $^{24}Na^{+}$ as well as $^{32}PO_4^{3-}$ ions applied to the peduncle in vivo moved exclusively towards the fruit. Only very small quantities of ions were translocated towards the mother plant; this being rather due to surface flow.

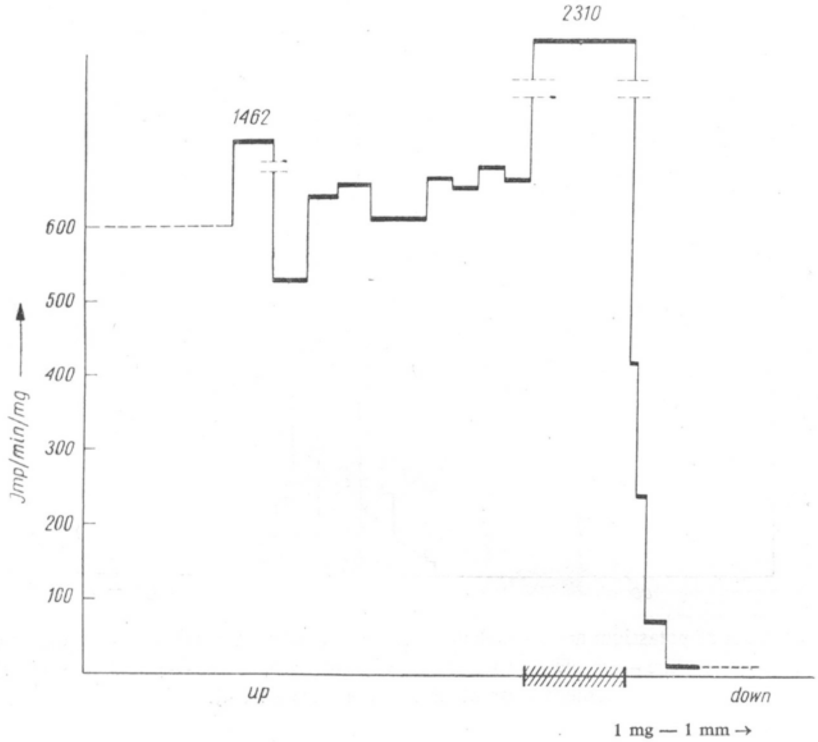

Fig. 4. Gradient of potassium content in fruit stem with a drop of radioactive substance applied on the surface of the stem not detached from the plant. The dry weight of the fruit stem expressed in mg is marked on the horizontal axis; the hatched section shows the site of application of the substance, the physiologically lower part of the stem is marked by an arrow. Specific radioactivity of the stem section expressed in imp-min^{-1}mg^{-1} of dry weight is marked on the vertical axis.

A typical result of an experiment with sodium is shown of Fig. 4, however, the number of experiments carried out with sodium and potassium (16) and agreement between them admits generalization of results. Phosphorus also moved towards the fruit only when applied to a slightly damaged surface of the peduncle. The results obtained indicate that K^+ and Na^+ penetrate through the epidermis of the peduncle and are translocated in the stream of nutrient substances to the fruit.

This flow could be induced in some way by the fruit, or the peduncle possesses the ability of transporting the material in one direction, or else the plant itself is capable of directing the nutrient substances to the fruit. To elucidate this a number of experiments in vitro were made.

b) Behaviour of radioactive potassium and phosphate in a cut off strawberry peduncle

The results of the series of experiments with potassium indicate that the section of a strawberry peduncle does not show polarity of potassium transport. Radioactivity spreads symmetrically from the site of dropping to a small distance (See

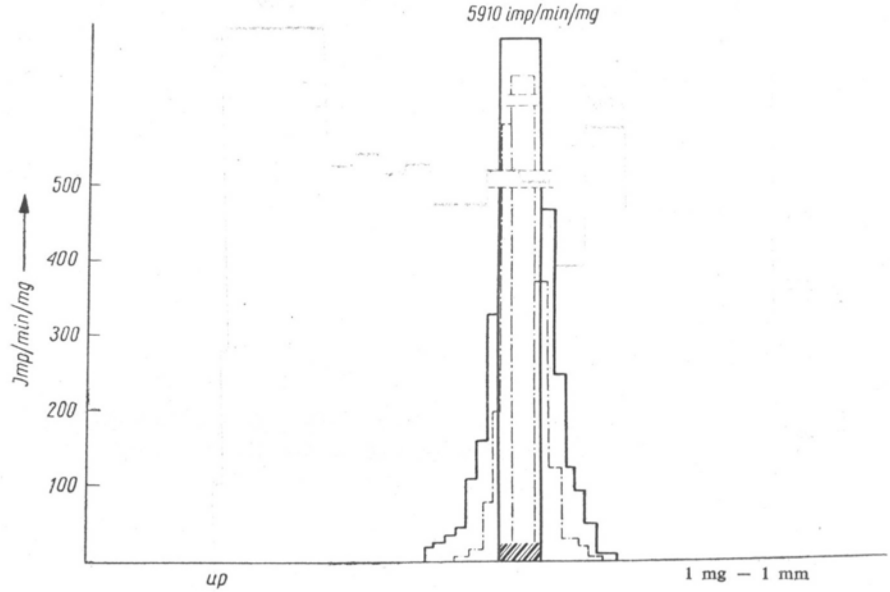

Fig. 5. Gradients of potassium and phosphate contents applied on the surface of fruit stem section in vitro. Continuous line — gradient of potassium content, broken line — gradient of phosphorus content (For other notations see Fig. 4).

Fig. 5). The distance on which the radioactive substance was translocated depends on the time of experiment.

An analogous experiment was made applying on a section of the peduncle a drop of $Na_2H^{32}PO_4$ solution. Since ^{32}P penetrated slowly through the epidermis of the peduncle, the former was damaged at the site of dropping. In these experiments the ends of peduncle sections were not immersed in water but stuck into agar cubes. The results were the same as for potassium (Fig. 5, dashed line). From the data obtained it can be inferred that in these conditions the translocation K^+ and PO_4^{3-} ions in the peduncle takes place only by way of diffusion. A peduncle cut off from the plant and fruit is not capable of transporting potassium and phosphates unidirectionally.

c) Transport of potassium and phosphate in a section of a peduncle with forced flow of water

The question arose whether it is possible to induce unidirectional transport of potassium by forcing water through a cut off peduncle. To elucidate this a series of experiments were made in which the water pump was connected to the end of the peduncle section as a source of hypotension. The substance was applied in the same way as described above (see Fig. 3) to the centre of the section. The result of such an experiment is shown in Fig. 6.

The results seem to indicate that forcing of water flow in the peduncle fundamentally changes the distribution of potassium in the investigated section. Potassium

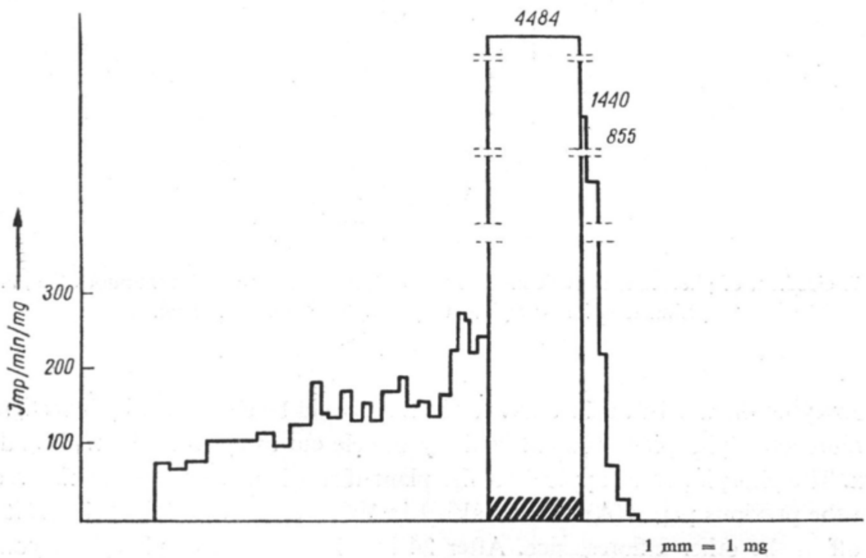

Fig. 6. Gradient of potassium content in a fruit stem section with forced flow of water (For notations see Fig. 4).

moves in considerable quantities towards the source of hypotension and does not travel at all towards the other end of the peduncle placed in water. The character of the distribution of potassium along the peduncle is similar to that observed in experiments in which the substance was applied in vivo.

Similar experiments were made with phosphates, by applying the substance dropwise on a damaged surface of the peduncle.

Also in this case $^{32}PO_4^{3-}$ moved in the direction of the source of hypotension. The flowing out liquid was radioactive but the peduncle showed on its whole length no, or only very small, radioactivity (of the order of 1—5 $imp \cdot min^{-1} mg^{-1}$) The site of application showed high radioactivity (several tens of thousands of $imp \cdot min^{-1} mg^{-1}$, also 3 to 4 sections located symmetrically from the point of application were active.

d) Gradient of phosphate content in the peduncle with fruit cut off

Since the fruit peduncles in vitro are not capable of unidirectional transport, the question arises what part — the fruit or the mother plant — disposes of the forces transporting the components. It appeared that the role of the mother plant

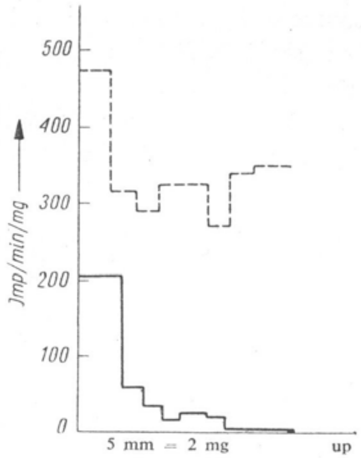

Fig. 7. Gradient of phosphate content in peduncle with receptacle cut off (continuous line) and in peduncle with carrying the receptacle (broken line).

in conveying the nutrient substances to the fruit could be elucidated by investigating the radioactive phosphate content in the peduncle cut away from the fruit and the calyx. The phosphate was applied to the plant through a transected in florescence as in the previous paper (Antoszewski, Lis 1967), at the same time the fruit was cut off in the other inflorescence. After 24 hrs the gradient of phosphate content in the peduncle was determined. The result of the experiment is shown in Fig. 7.

It was observed that the phosphate content in the peduncle decreases in the direction of its apex. This indicates that in the case when the fruit is cut away from the peduncle the plant cannot send phosphorus in this direction.

From all these data it can be concluded that the fruit itself can draw nutrient substances from the plant. It should be noted that the experiments were done in such conditions of soil and air moisture that guttation did not occur.

e) The influence of inhibition of fruit transpiration on its suction force

It seems that the pattern of distribution of potassium in the peduncle is due to a flow of fluid in it. This flow is released by hydrostatic hypotension produced by the fruit. One may ask what is the nature of the force enabling the fruit to exert considerable hypotension on the vascular system of the plant. Here

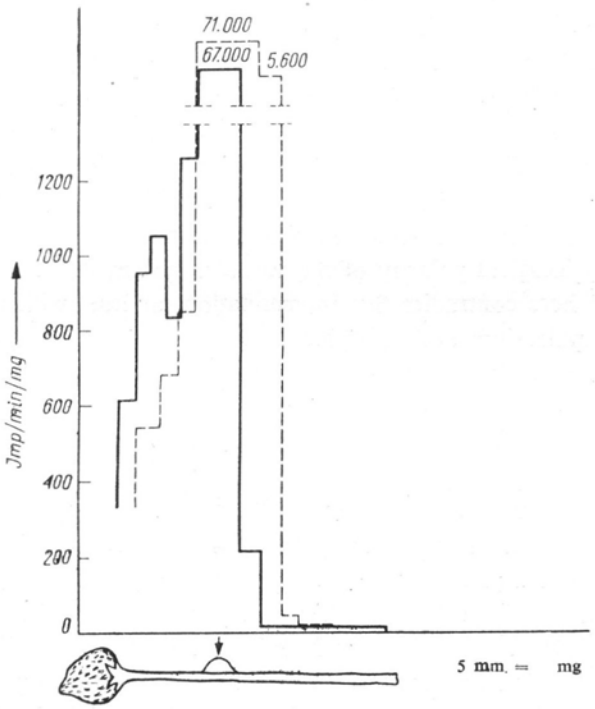

Fig. 8. Gradient of potassium content in peduncle with inhibited transpiration (continuous line) and in peduncle of a fruit allowed normal transpiration (broken line). The radioactive substance was applied on the surface of the peduncle in vivo.

the first thing drawing attention is the transpiration of the fruit. As known it has repeatedly been demonstrated that the fruit transpires intensively (Prokofiev, Kats 1964; Ozerov, Ozerova 1960). In order to determine the role of transpiration in this process, the fruit was immersed in liquid paraffin for about a dozen hours before the experiment, and the substance was applied to the peduncle as previously. Preliminary experiments showed that the fruit immersed in liquid paraffin for a long time does not change its normal appearance and when taken out of paraffin develops showing no particular damage. The experiment is illustrated in Fig. 1. The gradient of potassium in the peduncle of a fruit with inhibited transpiration is shown in Fig. 8 (continuous line). For comparison the gradient of potassium in the peduncle of a fruit in vivo is also given (dashed line).

As seen from the data shown in Fig. 8 exclusion of transpiration does not inhibit the inflow of radioactive potassium to the fruit, neither does it essentially change the potassium gradient in the peduncle. It can therefore be concluded that there is no direct relationship between the suction force of the fruit and its transpiration. The source of the suction force of the fruit is the subject of separate investigations.

DISCUSSION

The nature of the "key" according to which the nutrients are distributed in the plant organism is so far unknown (Górski 1962; Kursanov 1963; Nitsch 1965). This problem seems to be of particular importance for the understanding of the mechanism of functioning of organs which accumulate or consume the nutrient substances.

One of the factors responsible for control of the distribution of nutrient substances could be the physiological polarity of the vascular system itself. It seems that the results presented here contradict this interpretation, at least with respect to such ions as sodium, potassium and phosphate.

Particular attention should be given to the fact that forcing of water flow through the vascular system of the strawberry makes the pattern of distribution of the investigated substances in the peduncle similar to the distribution of these substances in vivo, that is when the fruit remains on the peduncle. This leads to the conclusion that the fruit exerts hypotension on the vascular system of the plant. The occurrence of such a hypotension in the vascular system of plants was described by a number of authors (Crafts 1949; Strebeyko 1956) and could be used for intensive labelling of plants with radioactive substances (Antoszewski, Lis 1967).

The next problem are the forces which elicit and maintain this hypotension. Transpiration which is frequently considered as the basic transport factor, is in this case not the main force, since its exclusion by immersing the fruit in paraffin does not essentially change the transport to the fruit. In fact we were successful in obtaining very fine strawberries after closing the pollinated flower in a sealed Erlenmeyer flask.

At present autohors lean to the opinion that the principal factor producing the suction force of the fruit is the hypotension appearing in the fruit tissues as the result of extension growth of this organ. If it is so, one might think that the growth correlations controlled by growth regulators secreted by the achenes shape the architectionics of the organ so that this hypotension is directed to the vascular system. The hypotension of the vascular system causes the flow of sap in the xylem. The sap carries away nutrient substances from the living components of the phloem. In the light of experiments on the forced flow of fluids through the fruit stem, the role of the xylem flow seems to be essential even if there is no root pressure. Such a low hypotension, as exerted by water pump, cannot change essentially the phloem stream because of considerable viscosity of the phloem sap. Besides, both the sodium and the potassium are transported rather in xylem and it is the hypotension that changes the picture of the distribution of sodium and potassium.

The less pronounced results of experiments with phosphorus are explained by the fact that it penetrates the surface tissues less rapidly and by the greater affinity of the living elements of the vascular system to the phosphate ion (Penot 1965).

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Badania nad ruchliwdścią $^{42}K^{+}$, $^{24}Na^{+}$ *i* $^{32}PO_4^{3-}$ *w szypułce truskawki*

Streszczenie

Badano transport radioaktywnych związków sodu ($^{24}NaCl$), potasu (^{42}KCl) i fosforu ($NaH^{32}PO_4$) w szypułce truskawki in vivo i w izolowanych odcinkach szypułki. Preparaty radioaktywne w roztworach wodnych nanoszono na powierzchnię szypułki.

Stwierdzono, iż in vivo transport badanych substancji odbywa się tylko w kierunku owocu, natomiast w izolowanych odcinkach szypułki substancje te przemieszczają się symetrycznie w obu kierunkach jak w procesach dyfuzyjnych. Przyłożenie podciśnienia z jednej strony szypułki powoduje takie przemieszczanie się badanych składników, jakie obserwowano in vivo, tzn. w kierunku przyłożonego podciśnienia (źródłem podciśnienia była pompka wodna).

Wnioskuje się stąd, iż w warunkach naturalnych owoc wywołuje podciśnienie w układzie przewodzącym rośliny. Działanie to nie jest bezpośrednio zależne od transpiracji owocu, ponieważ transport badanych składników w kierunku owocu nie ustaje nawet gdy owoc jest zanurzony w płynnej parafinie i nie transpiruje.