

THE EFFECT OF CENTRIFUGAL FORCE ON PLANTS.

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The first experiments made on plants with centrifugal force were performed by Knight¹ in the year 1806. His apparatus was simply arranged, was run by water power and the amount of centrifugal force that his machine produced was very small. His object was to observe the behavior of seedlings under a somewhat intensified gravitational force. Since the time of Knight some other investigators have investigated the action of centrifugal force on various plants and especially some of the studies have been made on seedlings. These are generally of such size or can be so selected, as to lend themselves advantageously to experimentation of this sort. Among the investigators who followed Knight in this field of study may be mentioned Müller² who made a study of the growth processes of roots when acted on by centrifugal force. As in the case of Knight the amount of centrifugal force which Müller employed in his experiments also was small. Ten years later the subject was again prominently investigated in a similar way by Elfing³ who also used only a small amount of centrifugal force. The amount of such force which Elfing used varied from 29-50g, which was slightly greater, however, than that employed by the above mentioned investigators. The original paper of Elfing I have not seen. An extract of its contents has been given by F. Schwartz in the *Botanische Zeitung* Bd. 39, 1881, P. 176 above referred to. At the same time that the paper of Elfing appeared a similar piece of investigation had been completed independently by F. Schwartz.⁴ This paper by Schwartz also appeared in 1881 from Pfeffer's laboratory in Tübingen. Schwartz worked with a specially constructed form of centrifugal machine which, however, did not use the ordinary form of revolving drum. Instead it was so constructed that it carried at right angles to the revolving main shaft, a second shaft that carried a number of boxes which contained the specimens to be investigated. These seedlings were grown in sawdust which, however, is objectionable in some respects to use in a machine of this type during experimentation. The boxes just referred to were so placed on the second shaft as to balance one another during centrifuging. Various other contrivances in connection with this machine were used and which I can not discuss here but will refer to them at a later period. Schwartz used control plants and the number of gravities employed by him was also small and did not exceed 30 gravities in any of his experiments. He as well as the other investigators did not observe a retardation of the growth of the seedlings used in their experiments. The use of the klinostat as used by Sachs or as originally constructed and used by Hunter and others in experiments performed by them does not apply in the preceding statements since

¹Knight, T. A. *Horticultural Papers* P. 124.

²Müller, N. J. C. *Die Wachsthumerscheinungen des Wurzel*. *Botanische Zeitung*, Bd. 29, 1881, P. 716.

³Elfing, Fred., *Beiträge zur Kenntniss des Physiologischen Einwirkung der Schwerkraft auf die Pflanzen*, *Botanische Zeitung*, Bd. 39, 1881, P. 176.

⁴Schwartz, F., *Untersuchungen aus dem Botanischen Institut zu Tübingen* Bd. 1, 1881-1825

the klinostat was used to annul or make omnilateral the force of gravity on growing stems and roots.

The effect of very high centrifugal force on plants has been investigated by only a few persons and with them the length of time the experiments were carried on was very short. I first began the study of the effect of very high centrifugal force on the growth of plants in Pfeffer's¹ laboratory in Leipzig and since then have concerned myself with the subject in general. It might be supposed that very high centrifugal force varying from 3,000 to 5,000 gravities would bring about a cessation of the growth of plants and probably kill the specimens. A careful study of this subject, however, has shown that this is not the case. The following remarks will give some data to show that the plant activities of the kind mentioned did not stop but actually continued although less actively. This was shown in the following way: Seedlings of *Cucurbita pepo* were grown until their roots were 3 cm. long. Four of these seedlings were then placed through a strong cork so that their roots projected into a strong glass cylinder which was 5 cm. long and 28 mm. in internal diameter. The cork rested on the open end of the cylinder by a shoulder-like projection and four places in this cork were hollowed out to receive the seeds. A small quantity of water was put in the bottom of the glass cylinders to retain the moisture necessary. Gypsum was poured over the part of the seed that projected from the cork and also around the seeds to hold them in place. In all these experiments when necessary gypsum was used to hold the specimens firmly in place. This method of using gypsum in plant experimentation was first used by Pfeffer and in the year 1892. I centrifugated the above mentioned specimens two hours using 4400 g. The plants were not killed, as stated, by this severe treatment but the growth was retarded. In those experiments where 4400 g. was used and centrifuging took place in air the amount of growth was decreased from 3.5 mm under normal conditions to 2.5 mm. When so centrifuged in water the roots grew on the average 2.1 mm. In the same way decreases in the rate of growth were observed in *Pisum* and *Helianthus* when a force of 4400 g. were used. In the same way I carried out experiments on other seedlings but sometimes using less force, as low as 2000 g. for periods first of two hours and then one, two, and in many cases as long a period of time as five days. In these experiments longer glass cylinders were used than in the first case. For example *Zea mays* grew on the average of sixteen plants with roots ten mm. long to begin with in two hours 3.3 mm in air when so centrifuged. In water they grew 2.65 mm. in two hours while the controls in sawdust grew 3.8 mm in the same time. With a higher centrifugal force of 5000 g. they grew about one-third less in the same time. For longer periods of centrifuging of one, two and up to five days the same effect was seen. The specimen centrifuged in water was killed by the water pressure at the end of the second day in this experiment. In some other experiments of this kind this did not occur. At the end of five days of centrifuging with 2000 g the sixteen plants averaged 77.2 mm in length while the control plants averaged 103.7 mm. Arrangements for changing the moisture and air in the cylinders was provided. These experiments might be carried on for a much greater length of time if properly arranged. This is sufficient to show, however, the severe tests which

¹Pfeffer, W, *Pflanzenphysiologie*, Zweite Auflage, Bd. 2, P. 567.

rather delicate plants of this kind can stand and finally recover. This they did, when planted, in about two weeks so that at the expiration of that time no difference was visible between the experimental and the control plants as seen above ground in the growth of the stem. In many cases the growth of lateral roots makes a very prolonged experiment impracticable. In each case when the roots were marked off in the usual way to show the growing region whose growth was lessened as shown by comparison the growth was not completely stopped in any zone. Other than that the growth was decreased in the growing zones the regions and relation of growth to the controls remained the same. Many more experiments have been made on other plants which confirm these points. The centrifugal force therefore used by Schwartz and Elfing and others did not cause a noticeable difference simply because it was not of sufficient intensity. In all the experiments which I performed the contents of all the cells was thrown to the centrifugal end of the cell. It returned to its normal position in the various cells whether they were large or small after two to three days. Even after the contents had returned to its normal position, as indicated above, a much longer time was still necessary to allow the complete shock of the centrifugal force to disappear. This varied according to the plant and the intensity of the centrifugal force.

