On the Movements of the Flowers of Sparmannia africana, and their Demonstration by means of the Kinematograph.

BY

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With Plates XXXVII, XXXVIII, and XXXIX.

SPARMANNIA africana is a common greenhouse plant, which was introduced from the Cape into Europe as early as 1790. It was named after Dr. Sparmann, a Swedish botanist, who accompanied Captain Cook on his second voyage round the world.

It belongs to the order Tiliaceae; there are three species: *S. abyssinica*, *S. palmata*, and the subject of the present paper.

It is well known to the botanist on account of the curious movements of its stamens, which, when touched, gradually move away from the style, leaving the stigma exposed and ready for fertilization by bees.

A paper was written on the subject as early as 1841 by Charles Morren[1].

S. africana is found wild in many parts of S. Africa, occurring about the Knysna district and from thence East, but always at no great distance from the coast. It attains a height of about 15 feet, ripening its seeds towards the end

[1] Mém. de l'Acad. Roy. de Bruxelles. Ch. Morren, 1841, vol. xiv.

[Annals of Botany, Vol. XVII. No. LXVIII. September, 1903.]

of October or beginning of November and again in March. It is found at the edges of forests outside the tree belt.

All my investigations were made on plants growing in a greenhouse. In its natural state the day temperature during flowering rises to a maximum of 92° F. (33° C.); but it is seldom more than 80–87° F. (27–30·5° C.), and the nights average about 60–65° F. (15·5–18·5° C.), seldom falling lower than 57°F. (14°C.)[1].

The whole plant is covered with hairs, which protect it during the cold nights on its native mountains round the Cape. The young buds are themselves covered with dense hairs, and are sheltered at an early age by the hairy leaves above them (Fig. 13).

Sparmannia africana is an exceptionally favourable plant on which to study reaction to stimulus, as so many of its parts are sensitive. The most strikingly sensitive organs are the stamens: these are arranged in four groups, having an outer circle of staminodes. Both stamens and staminodes are provided with curious tooth-like outgrowths, few in number on the stamens, but becoming more and more numerous and conspicuous as the outer staminodes are reached. All of these are sensitive to touch; if only one stamen be touched, the stimulus spreads until all the stamens and staminodes have moved outwards away from the stigma.

These movements have been described in great detail by various writers[2].

Then the petals and sepals respond to the stimulus of light, and lastly the flower as a whole is capable of special movements, regulated not merely by the curvature of the pedicel, but by the action of the pulvinus or joint situated at a short distance below the flower.

The following observations, which extend over two seasons, are principally on the movements of the flower bud and flowers up to the time of the setting of the fruit.

Three complete inflorescences from bud to fruit were drawn

[1] I am indebted to Mr. Harry Bolus, of Cape Town, for these details.

[2] Haberlandt, Sinnesorgane im Pflanzenreich, pp. 46–51. Leipzig, 1901.

every day and night, and from these data the following results were obtained:

The inflorescence is an umbel. At first the buds hang all on one side of the main peduncle, both buds and pedicels are densely hairy. The pedicel of each bud is jointed. This curious joint or pulvinus is situated at an average distance of about 1 cm. from the bud, and will be found to be much swollen on the side away from the bud. The swelling becomes more noticeable as the bud grows older and the functions of the joint come into play.

This joint, which is present in all three species of *Sparmannia*, bears in its action and structure some resemblance to the pulvinus found on such leaves as those of the sensitive plant (*Mimosa pudica*), and helps to regulate the position of the bud, flower or fruit at different times of its development. It is capable of causing the most delicate movements of the bud or flower, and responds readily to the stimulus of light.

The greenhouse plant is specially favourable for the study of the joint. Owing to the fact that *Sparmannia africana* is used as a winter flowerer here, the flowers open much less readily than they do in their natural state. This can be easily seen, if a dried wild specimen be compared with one from a greenhouse. In the specimens in the Kew Herbarium one frequently finds flowers and ripe fruits of which some have already fallen on the same umbel, and very often (see Pl. XXXVII, Fig. 14) an umbel has nine or ten open flowers at a time, while in the greenhouse specimen quite frequently days pass without a fresh flower opening, while in one umbel drawn, the last flower lost its petals on March 19 and the first fruit was not ripe till April 25. So that a joint, which under natural conditions might only be used for a few weeks, will in a greenhouse specimen have to remain active for as many months.

Thus the joint develops by use, and, after a cold month, when the temperatures have been too low to admit of the flowers opening, becomes quite a conspicuous feature of the plant.

The peduncle circumnutates and grows during flowering on an average $1\frac{3}{4}$ inches ($4\frac{1}{2}$ cms.) in height, and the flower-bud rises 3 inches ($7\frac{1}{2}$ cms.) in height.

These results were arrived at by means of a diagram made by careful daily measurements on a cylindrical glass enclosing the inflorescence.

Figs. 1–12 represent stages in the development of an inflorescence, and are drawings selected from a continuous series beginning on March 6 and ending July 23, 1902, drawn every day and every night during flowering.

If Fig. 1 is first examined, three buds will be seen moving up into the flowering position; we will first follow the behaviour of bud 3, in Figs. 1, 2, and 3, as this has only just started from the pendent position parallel to the main peduncle. The first drawing of bud 3 was made at 11 a.m. March 6, temp. 63° F. (17·5° C.) on a fine sunny day, and the movement of the pedicel was very rapid; the amount of movement attained by 4 p.m. is shown by the dotted lines in Fig. 1. Here it will be seen that the whole pedicel is straightening itself; it continues to rise in this way all through the night (Fig. 15 represents the position of a similar bud at 4.30 a.m.), until on March 7, 10 a.m. it had attained the position shown in Fig. 2. The pedicel then makes a sharp bend as seen in Fig. 3 (or better in Fig. 31) the bud is dropped into the vertical position ready for flowering by the movement at the joint (see Fig. 5 where 3 is in flower), and in Figs. 1 (bud 1), 52, 55, 58. The exactness of the vertical position attained is very remarkable; no doubt the opening bud has its stamens protected from injury till the last minute before opening by this means, and, if rain falls, the hairy sepals are in the position of an umbrella, ready to throw it off, without injury to the more internal parts of the flower. We must now follow the opening of the bud. (Figs. 22–25, 30–39, 58–64 show this process.)

The bud on a hot day begins to open as a rule a short time before sunrise. For instance, on the morning when the sun rose at 6.32 a.m. March 8, at 5.45 a.m. I found the buds breaking open on all sides temp. 50° F. (10° C.), till at sunrise they had attained the position shown in Figs. 35 and 59. Up till now the stamens have not been exposed ; now for the first time a few of the staminodes raise themselves and begin to show between the petals (see Figs. 23, 24, 56 and diagram), and the rapidity with which the flower opens from this stage depends on the temperature. If it is sunny and has reached about 60° F. (15·5° C.) by then the process of unfolding is so rapid that it is difficult to draw the different stages (an example of this rapid opening is shown in Figs. 22–25) where the time interval between 23 and 24 is only ten minutes ; but if, on the other hand, the temperature remains low, these little hooked staminodes, which are now raised into the position in which they will be in an open flower, appear to be peculiarly sensitive, and from observations made later seem to transmit a message to the other parts of the flower, causing it to finish opening as soon as the temperature is right. They are a most conspicuous feature in a flower during the critical moments of its opening and closing, but even when a flower is opening rapidly, if carefully watched, one can see that these staminodes are raised first.

The flower continues to open gradually, the petals becoming less and less crumpled, the sepals and petals rising one by one (see Fig. 24) until eventually on a sunny day the sepals are pressed tightly back and the petals raised to the utmost, exposing the stamens (Figs. 5 (2 and 3), 25, 39, 64). The style is at first shorter than the stamens, but by the following day has grown to their length. If very cold weather prevails, and the flower is prevented from opening for some days, then the style is found to be its full length as soon as the flower opens.

The opening is generally complete by about 9 a.m. The flower remains wide open during sunlight ; as the sun's power diminishes, the flower-stalk moves from the joint until the flower again reaches the vertical position (Fig. 4), the petals close over the stamens one by one (see Fig. 15, one flower has one petal closed, the other two and Figs. 16–20), then the sepals close too, and the flower shuts for the night (see Fig. 4 (2), where the flower 2 in Fig. 3 is seen closed and the older flower 1 has just been dropped into the vertical position preparatory to closing. Also Fig. 6, where flower 3 in Fig. 5 is closed).

The first day then the flower is small, has a short style, and generally closes about 6 p.m. (see Figs. 25, 53, and 63).

On the second day the flower begins opening much earlier than on the first occasion—5 a.m. (when sunrise is 6.32 a.m.), and opens so rapidly that it is difficult to follow its movements. The style has grown as long as the stamens, which are now very sensitive, and at the slightest touch move rapidly away from the stigma. The flower is closed by 9 p.m. (see Figs. 54 and 64).

The third day the flower again opens as before, the stamens are still sensitive, but the flower is *very late* going to sleep. At 10.30 p.m. the petals had fallen into the flat open position (Fig. 4, 1), at 11.30 one petal was closed, and it was not until 4.30 a.m. that the flower was completely shut.

The fourth day the flower is flat open, and again goes to sleep late. The fifth day the flower does not open so widely, and the stamens are no longer sensitive. At the time when the other flowers are shutting for the night, it shuts slightly but never reopens. Gradually it closes more and more, and during this time it is gradually attaining the vertical position (see Fig. 5, Flower 1, which in Fig. 6 has shut and will not reopen.) In Fig. 7 it has almost attained the vertical position.

As the flower withers, if bees have not been plentiful the pollen is mechanically extruded from the stamens. This is the usual course of a flower's life, when fertilization has not taken place. It varies to a certain extent according to weather conditions. For instance, sometimes a flower does not reopen in the position of the second day, but at once takes up the flat open position of the third day.

The progress of the flowers from day to day is very difficult to watch accurately. The flower of to-day takes up the position occupied by yesterday's flower. This was well brought out by plotting the flowers as explained on p. 764, where it was found that the flowers in succession occupied one another's places, so that unless each flower be accurately drawn daily it would be very easy to confuse the identity of the individuals.

I will now describe the progress of a fertilized flower, Fig. 8, Flower 9.

This opened first at 2 p.m. on March 12.

Closed 6 p.m.

Second day. Bees were introduced into the greenhouse, and the flower was fertilized (Fig. 21). Stigma as long as the stamens.

Began going to sleep 8.45, March 13.

The flower continued to open and close on the 14th, 15th, not beginning to close on the 15th until 10 p.m. After this it gradually closed its petals, whilst moving up into the vertical position. On March 18, six days after it first opened, the whole pedicel moved down from the vertical into the horizontal position (Fig. 9, Flower 9); the flower was turned up vertically by movement at the joint. The fertilized flowers always behave in this way, thus getting out of the way of the buds and open flowers.

On March 19 the flower still opened a little, the pollen was ripe and plentiful, and the pedicel was gradually moving up again. The petals now fell off, the stamens withered and the fruit swelled. It was ripe in June (Fig. 11). A layer of periderm is formed at the joint, and it is here that the fruit detaches itself when ripe (Fig. 14, a figure drawn from a herbarium specimen). The seed was sown on June 22, and the seedling came up and was figured on July 23 (Fig. 12).

The ovules are capable of being fertilized in cold weather also. I have one example of a fertilized ovule (Jan. 8) with endosperm, but the fruit cannot ripen under these conditions. Temperature about 40° F. (4·5° C.).

If we now review the general movements of the umbel, we shall see that the arrangement is such as to ensure an even distribution of the flowers and afterwards of the fruits over the sphere of the umbel, so that each flower or fruit is separated from its fellows and is exposed to the best advantage to the sun's rays. The buds when young hang down close to the peduncle out of the way. As the flowers open they rise, and again move out of the way into a close vertical cluster after fertilization. Then the fertilized flowers move down one by one into the horizontal position, and gradually rearrange themselves equally over the sphere during ripening; the last fruit remaining in the vertical position.

The whole development from bud to seedling thus occupied four months; this is no doubt a very much slower process than it would be under natural conditions. As the flowers only open well during sunlight with a temperature of about 60° F. (15·5° C.) and the plant is flowered in our early spring, one often gets only one flower at a time on an inflorescence, and many days may elapse before another has the opportunity of opening, while on a hot day one may get three or four fresh flowers opening at the same time.

The plant flowers again six months later, in September, though it is seldom given the opportunity here, as the usual treatment is to cut it back after the early flowering.

The opening of a normal bud has now been described, but the weather conditions make very considerable alterations in the habits of the bud.

The opening is retarded by fog, probably principally because fog tends to keep down the temperature, which must be about 60° F. (15·5° C.) for a flower to open. The bud will not go on opening if for any reason the temperature falls.

One bud (Figs. 42 and 43) began opening at 10.50 a.m. temp. 72° F. (22·5° C.) on a bright sunny day. At 11 a.m. it put up two sepals (Figs. 44 and 46); at 12.10, temp. 66° F. (19° C.), it was putting up a third (Figs. 47 and 48) when a hailstorm reduced the temperature below 60° F. (15·5° C.) [1]. This is the stage at which in the normal opening the stamens

[1] The hailstorm no doubt reduced the temperature much more than would have been the case in the open, as the glass of the greenhouse was made wet and cold by the falling hailstones, and the evaporation afterwards tended still further to make the temperature fall.

begin to expand, but here only a few staminodes were protruded and erected from between the petals (Fig. 50).

This happens so constantly when a flower is checked in opening (see Fig. 56) that it seems as if in some way the delicate projections from the filament must be more sensitive to temperature changes than the rest of the flower, and are perhaps able to send a message to the other parts. At 12.40 p.m. the temperature again rose above 60° F. (15·5° C.), and it put up a third sepal (Figs. 49 and 50) at 2.20 p.m. Another hailstorm so reduced the temperature that the flower closed for the night (Figs. 51 and 52). Figs. 53 and 54 show it open the next and following mornings. In Fig. 53 the style will be seen to be short, while in Fig. 54 (drawn the following day) it had grown to the length of the stamens.

Another flower (Fig. 55), which began opening at 10 a.m., kept one sepal up (Figs. 55–57) till 12.30 p.m., and then a hailstorm lowered the temperature, and it closed for the night (Fig. 58).

I watched one flower on Nov. 20, which had been trying to open for three days; this had developed the most conspicuous joint, which I ever observed.

On warm sunny days the buds go on developing, and one sometimes has the good fortune to be able to watch the whole process of opening without getting up before sunrise. Figs. 22–25 show a flower, which began opening at 12 p.m. and was full open at 2.5 p.m., closed at 6 p.m. Note in Figs. 23 and 24 the staminodes rising above the first opened petal.

The so-called 'sleep' of these flowers is a very interesting and variable process, and probably has some connexion with their fertilization, as the flowers no longer close well after the stamens have ceased to be sensitive. The plant is very active at night. The buds move upwards and outwards in the most vigorous way all night, and the style also grows in length during the night, so that a one-day-old flower, which had a short style on closing about 6 p.m., has on opening the following morning a full-grown style as long as the stamens.

Effect of Rain on the Flower.

Kerner describes the effect of rain on the flowers of *Sparmannia africana*[1]. He says: 'The flowers are inverted and their anthers are turned towards the ground and covered over by the petals. When the flower is open, however, the petals are slightly tilted back, i. e. upwards. The margins of the petals overlap one another, and their outer surfaces, which in consequence of the inverted position of the flower are uppermost, thus form a basin open to the sky. When it rains this basin placed above the anthers fills with water, thus adding to the weight borne by the stalk, and as drop after drop increases the strain upon the latter, a point is at length reached when the basin tips over, letting the water flow over its edge, without wetting the stamens suspended beneath it.'

I have repeated this experiment; Fig. 26 shows the position of the flower before the rain-shower, Figs. 27 and 28 after the rain has begun. For a long time the cup fills and empties, shooting out the water in the direction of the arrow in Fig. 28 in a most perfect manner, and the stamens remain perfectly dry. The long, dense hairs of the sepals which form the cup also help to throw off the water rapidly. But if the rain is long continued or very heavy, the stamens eventually get wetted, as seen in Figs. 27 and 28, where the drops can be seen running off the stamens, which are hanging together in groups. Fig. 29 represents the same flower shutting up at 7 p.m. I found that if the stamens were once wetted the flower did not reopen, though if they kept dry they opened as usual the following day.

Chloroform Experiments.

One flower was chloroformed for a few seconds ; the stamens were no longer sensitive, but recovered their sensitiveness again after a short lapse of time.

[1] Kerner von Marilaun, A., Eng. Ed. 1895, vol. ii, p. 119.

A young inflorescence with all flowers in bud was chloroformed next, and the results watched. No apparent change took place, but the development of the inflorescence was very curiously affected.

The drooping buds went straight up into the vertical position, the position which the flower assumes after fertilization. The open flowers behaved in various ways: One took up the vertical position, whilst others moved down into the horizontal position, as in Fig. 9, 9. Some of the buds did not open at the usual time, but the style grew in length, as would have been the case normally the day after the opening of the flower. These buds presented the most abnormal appearance, with the stigma hanging out, though the sepals were quite closed. One bud measured 1 cm., and the style projected 6 mms. from it. In some cases, after a few days, the flowers fell off at the joint.

The effect of the chloroform seems to have been to make the buds and flowers lose all count of time. A bud, after recovering from chloroform, often missed out several stages of its development, another would grow a long style as if it were a two-day-old flower, while an open flower would take up the position of a fruit, or fall off at the joint, as if it were a ripe fruit.

The difficulty in carrying out these experiments is that it is so very easy to give too much chloroform and poison the inflorescence so that it never thoroughly recovers; in these cases other inflorescences are generally affected too.

Kinematograph Experiments.

It struck me that the inflorescence of *S. africana* would be admirably adapted for an experiment with the kinematograph.

The inflorescence could be photographed at intervals while young, so as not only to show the opening and the closing of the flowers and the movements of the stamens, but also the development of the inflorescence from bud to fruit. The series of photographs taken could then be projected with the lantern on the screen, and the development of the inflorescence, which in reality takes several months, could be watched in progress and could pass before the spectators on the screen in a few minutes, until the buds first shown had become fruits.

The difficulty of trying this experiment was principally one of expense.

Professor Pfeffer [1], of Leipzig, has made many successful botanical demonstrations with a kinematograph and has devised a very perfect apparatus for class demonstration, but the expense of his apparatus (exclusive of the cost of his original experiments) is too great to make it possible for use by the private investigator; one of the most serious items being the cost of production of each film, which amounts, Prof. Pfeffer tells me, to ninety marks (£4 10*s.*), while the apparatus for taking the photographs cost £45 (exclusive of the kinematograph and lantern for demonstration).

I at first experimented with a small film kinematograph, but the results were not satisfactory, as the machine was not suitable for making time exposures, and the makers were unwilling to help adapt their machine for scientific work. Also the life of the films when obtained was so short. The following experiments were made with a machine called the Kammatograph, in which the photographs are taken on a glass disc instead of on a film. In the use of this machine I have received every possible help from the inventor [2] of it, who has done his best to adapt it in every way for the work.

A short description of the machine will first be necessary to those who have not seen it. A glass disc of 12 inches in diameter is suspended in a metal ring; this disc is coated with a sensitive emulsion, and is in fact a large circular dry plate ready for use in photography, capable of taking 350 photographs. (Half one of these plates, after the photographs have been taken on it, is shown in Fig. 65, Pl. XXXIX.)

[1] Jahrbuch f. wiss. Bot., 1900, vol. xxxv, p. 38.

[2] Messrs. Kamm & Co., 27 Powell Street, E.C.

This glass disc, when ready for use, is put into a light-proof box, and by means of a handle at the side can be spirally rotated, so that every part of it is in turn exposed before the small oblong opening in front of the lens. In ordinary kinematograph work the handle is rotated at a uniform speed, and a series of snapshots are produced, but for the work now required it is necessary to take time exposures, as the light in a greenhouse would seldom, if ever, be good enough for instantaneous photography, and also, if it were possible, the number of photographs thus obtained would be unnecessarily large; as a large number are only required when rapid movement, such as that made by the stamens when touched or when a bud is opening, is taking place. For many parts of the day a photograph taken every quarter of an hour is sufficient.

The practical difficulties were very great; the principal ones were:

(1) To obtain absolute rigidity of the apparatus.

(2) Uniform exposure for each photograph, as photographs had to be taken at all times of the day and night and in all weathers.

(3) The difficulty of having some one always watching the plant.

(4) Compensating accurately for the growth in length of the inflorescence, so that the part of interest is always in the field.

The first difficulty was removed by the construction of a heavy metal tripod stand.

The second was soon removed by the use of an accurate actinometer, which must, however, be used for almost every photograph to ensure perfect results. The night photographs can be taken by means of a magnesium wire, accurately measured in lengths, or better still, by those who have electric light installed, with an arc light.

For the third difficulty I am afraid there is no solution but the adoption of an elaborate and costly automatic mechanism. This has been done by Professor Pfeffer.

It certainly would be a great advantage to be able to take photographs mechanically through the night, as unfortunately this plant, so far from following the human habit of sleeping through the night, seems to be peculiarly active between the hours of 1 and 5 a.m.

For the overcoming of the fourth difficulty I am indebted to Mr. Kamm, who constructed a very accurate sight to the machine, by the use of which the elevation could be readjusted every morning.

I will give a brief account of the kinematograph picture illustrated, Fig. 65. It was begun at 8.30 a.m. March 6, 1903. As many photographs as possible were taken of the bud while opening; then it remained more or less stationary for some time, and photographs were only taken at half-hour intervals until the flower began to go to sleep, when regular photographs were again taken with longer and longer time exposures as the light decreased, and then by means of magnesium wire. The following morning photographs were taken by magnesium wire from 4.30 a.m. until sunrise (see Fig. 66), when time exposures were again taken. To show the movements of the stamens when touched, instantaneous photographs were taken by turning the handle of the machine as in ordinary kinematograph work.

After two days' work another difficulty arises—the flower-stalk elongates, so that if a new adjustment is not made one finds the future photographs show only the stalk. This is remedied by raising the stand of the Kammatograph with the help of a very accurate sight adjustable for any distance above 9 inches, and then starting again. Of course one loses the growth of the flower-stalk, but this is inevitable, unless a much larger photograph is taken, which would involve a much more costly machine.

The sensitized plate is then removed and developed just like an ordinary plate, and when dry the positive is printed from it in a few minutes.

I must here state the one drawback to the use of this machine: there is no means of remedying a mistake.

With the film kinematograph over- or under-exposure, or a photograph which has been spoilt by accidental movement, has only to be missed out when printing, or if necessary the next photograph can be printed twice.

On the other hand this machine has great advantages. The developing of the whole series of 350 photographs only takes the same time as that required for developing any ordinary sensitive plate, and printing is also perfectly simple, as the negative is simply placed on a positive plate exposed for a definite number of seconds to the light of a lamp and then fixed. Any number of positives can thus be made by an ordinary photographer with a very small expenditure of time. The cost of producing each negative is 3*s.* 6*d.* and each positive costs the same amount, so that each subject taken costs 7*s.*

My experiments with both kinematographs extend over more than a year, and I have only quite recently succeeded in producing fairly good results ; but I think that most of the principal practical difficulties are now surmounted, and that the machine is in a fit condition for experimental work.

I have used it successfully for other subjects, such as climbing plants, to show the movements of the leaves of the sensitive plant.

I believe these are the first kinematograph experiments under natural conditions, daylight being used and artificial light only resorted to at night. It was thus possible to leave the plant undisturbed throughout the time of observation.

I am indebted to Miss M. Smith, of Kew, for kindly drawing two figures for me from photographs.

I am making microscopical investigations of the parts of the plant connected with movement, which promise some interesting results, but have thought it better to defer this to another paper, which I hope to publish shortly in conjunction with Miss Richards of the Royal Holloway College.

DESCRIPTION OF FIGURES IN PLATES XXXVII XXXVIII, AND XXXIX.

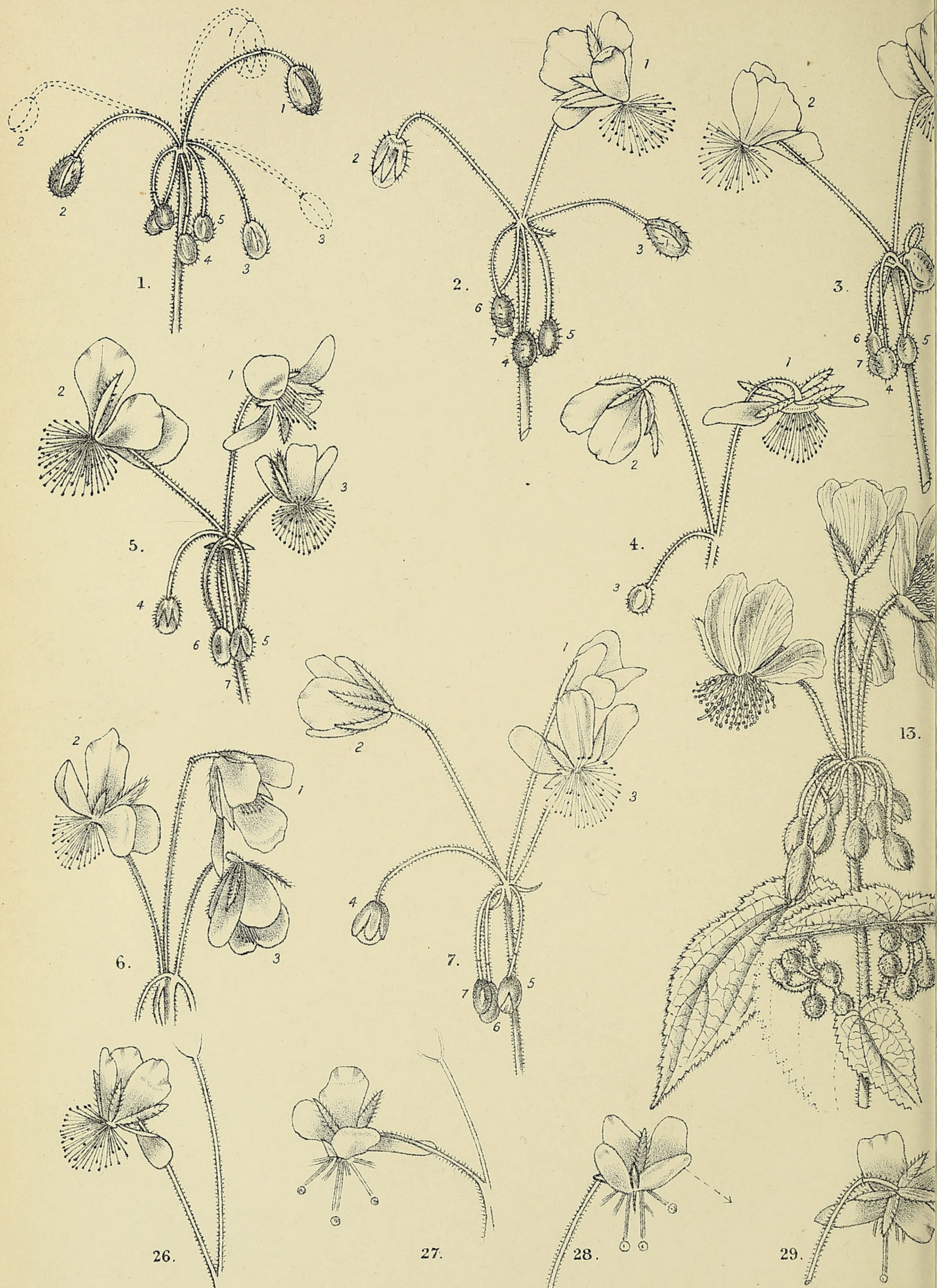
Illustrating Mrs. Scott's paper on *Sparmannia africana.*

Fig. 1. March 6, 60°, 11 a.m., sun out, dotted lines, 60°, 4 p.m., sun out.
Fig. 2. „ 7, 57°, sun out, 10 a.m.
Fig. 3. „ 8, 57°, sun out, 9.30 a.m.
Fig. 4. „ 8, 55°, 8.50 p.m.
Fig. 5. „ 9, 70°, sun out, 10 a.m.
Fig. 6. „ 9, 62°, 9.15 p.m.
Fig. 7. „ 10, 56°, dull, 10 a.m., flower 3 shut, 10 p.m.
Fig. 8. „ 15, 68°, sun out, 11 a.m.
Fig. 9. „ 18, 58°, „ 2 p.m.
Fig. 10. April 25, 68°, „ 3 p.m.
Fig. 11. June 22, 7.30 p.m.
Fig. 12. July 23, 1902, seedling sown June 24, 1902. G–G level of ground.
Fig. 13. Shows buds covered by leaf, from photograph.
Fig. 14. Drawing of ripe fruit from Kew Herbarium of wild *Sparmannia.*
Fig. 15. Drawing from kinematograph photograph, showing bud rising at night while flowers are closing.
Fig. 16. Sleep position, 7.30 p.m., 56°, 2 petals shut.
Fig. 17. „ „ 8.30 p.m., 55°, 1 petal shut.
Fig. 18. „ „ 9.10 p.m., 54°.
Fig. 19. „ „ 7.30 p.m., 56°.
Fig. 20. „ „ 9.10 p.m., 54°.
Fig. 21. Bees fertilizing flowers, 11 a.m., 65°, March 13, 11.40 a.m., 65°, flower bud began opening.
Fig. 22. 12 p.m., 70°, March 25.
Fig. 23. 12.50 p.m., 69°.
Fig. 24. 1 p.m., 70°.
Fig. 25. 2.5 p.m., 72°, asleep 6 p.m.
Fig. 26. Position of flower 12 p.m., 55°, before rain.
Fig. 27. „ „ after rain, March 4, 1902.
Fig. 28. „ „ „ „
Fig. 29. Same flower at 7 p.m., 52°, „
Fig. 30. 1 b, 10 a.m., March 22, 60°, sun out.
1 c, „ „ 22, „ „
Fig. 31. 2 b, 1 p.m. „ 22, 63° „
2 c, „ „ 22, „ „
There was a hailstorm at this time, and the flowers did not open further.
Fig. 32. 3 b, 6.45 a.m., March 23, 48°, sun out.
3 c, „ „ 23, „ „
Fig. 33. 4 b, 7.20 a.m., „ 23, 50°, „

Fig. 41. 4 c, 7.20 a.m., March 23, 50°, sun out.
Fig. 34. 5 b, 9 a.m., ,, 23, 55°, ,,
5 c, ,, ,, 23, ,, ,,
Fig. 35. 6 b, 9.5 a.m., ,, 23, ,, ,,
Fig. 36. 7 b, 9.10 a.m., ,, 23, ,, ,,
Fig. 37. 8 b, 9.20 a.m., ,, 23, ,, ,,
Fig. 38. 9 b, 9.30 a.m., ,, 23, ,, ,,
Fig. 39. 10 b, 9.45 a.m., ,, 23, 60°, ,,
Fig. 40. 11b, 11.50 a.m., ,, 25, 55°, ,,
6 c, ,, ,, 25, ,, ,,
Fig. 42. 1, 10.50 a.m., ,, 21, 72° ,,
Fig. 43. Other view, ,, 21, ,, ,,
Fig. 44. 2, 11 a.m., ,, 21, ,, ,,
Fig. 45. 3, 11.20 a.m., ,, 21, 68°, ,,
Fig. 46. Other view.
Fig. 47. 4, 12.10 p.m., ,, 21, 66°, ,,
Fig. 48. 5, 12.40 p.m., ,, 21, 66°, ,, other view.
Fig. 49. 6, 2.20 p.m., ,, 21, 60° (violent hailstorm).
Fig. 50. Other view, ,, 21 ,, ,,
Fig. 51. 7, 8.30 p.m., 52°.
Fig. 52. ,, ,,
Fig. 53. 8, 10 a.m., March 22, 60°.
1 a, ,, ,, 22, ,,
Fig. 54. 9, 1 p.m., ,, 22, 63°.
Fig. 55. 2 a, 11.30 a.m., March 22, 68°.
Fig. 56. 3 a, 12.30 p.m., ,, 22, 63°.
Fig. 57. 3 a, ,, ,, ,, ,, other view of 56.
Fig. 58. 4 a, 8.30 p.m., ,, 22, 58° ?
Fig. 59. 5 a, 6.40 a.m., ,, 23, 48°.
Fig. 60. 6 a, 6.45 a.m., ,, 23, ,,
Fig. 61. 7 a, 7 a.m., ,, 23, ,,
Fig. 62. 8 a, 7.10 a.m., ,, 23, 50°.
Fig. 63. 9 a, 7.35 a.m., ,, 23, 51°.
Fig. 64. 10 a, 9 a.m., ,, 23, 55°. (Sunrise March 23, 5.58 a.m).
Fig. 65. Half circle of kinematograph plate reduced.
Fig. 66. 5 successive photographs enlarged, the first four, from below upwards, taken by magnesium light.

The lettered numbers, e.g. 1 a–10 a, indicate series of figures taken from the same flower-bud.

The figures 1–64 were drawn natural size and reduced to $\frac{4}{5}$.



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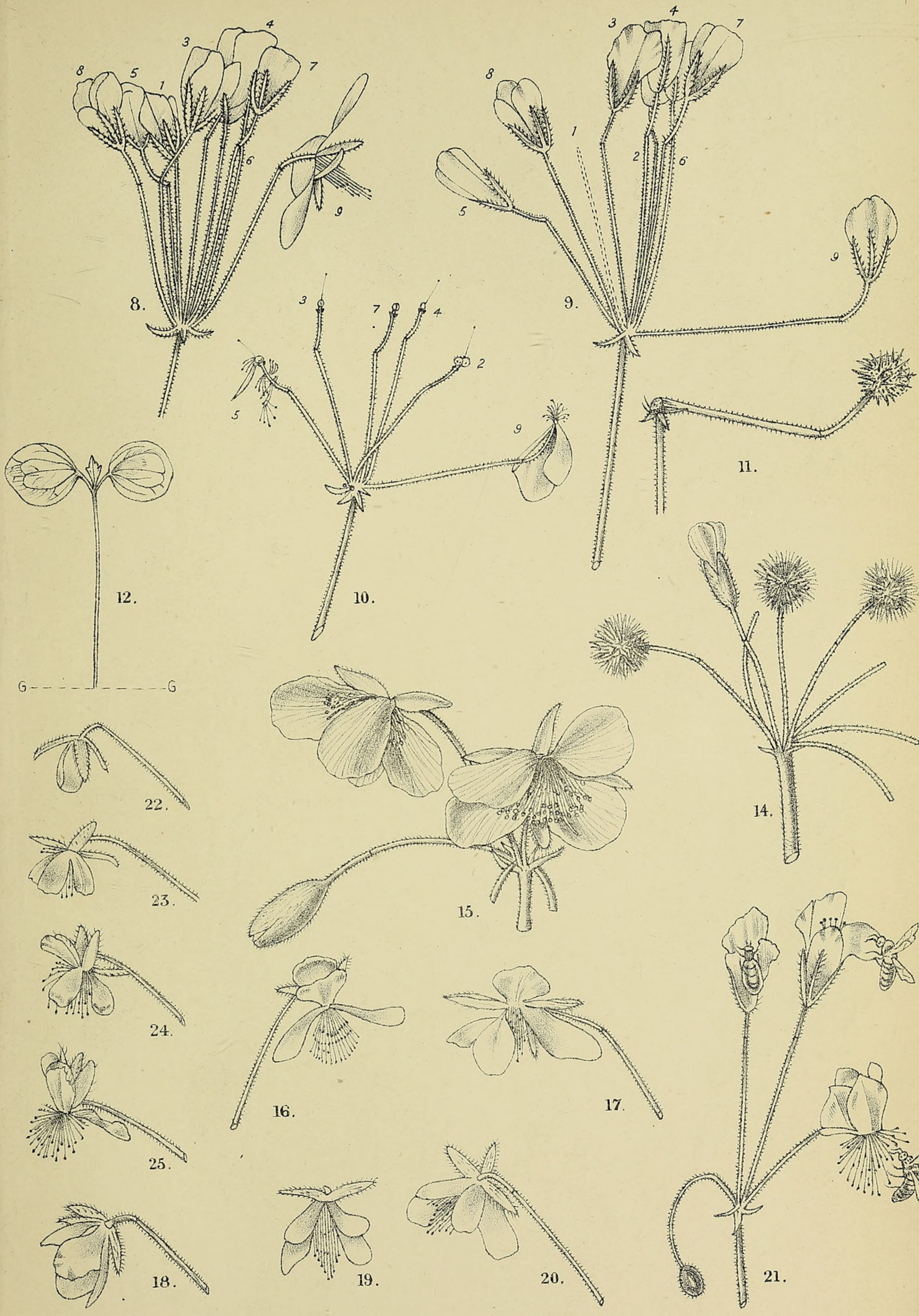

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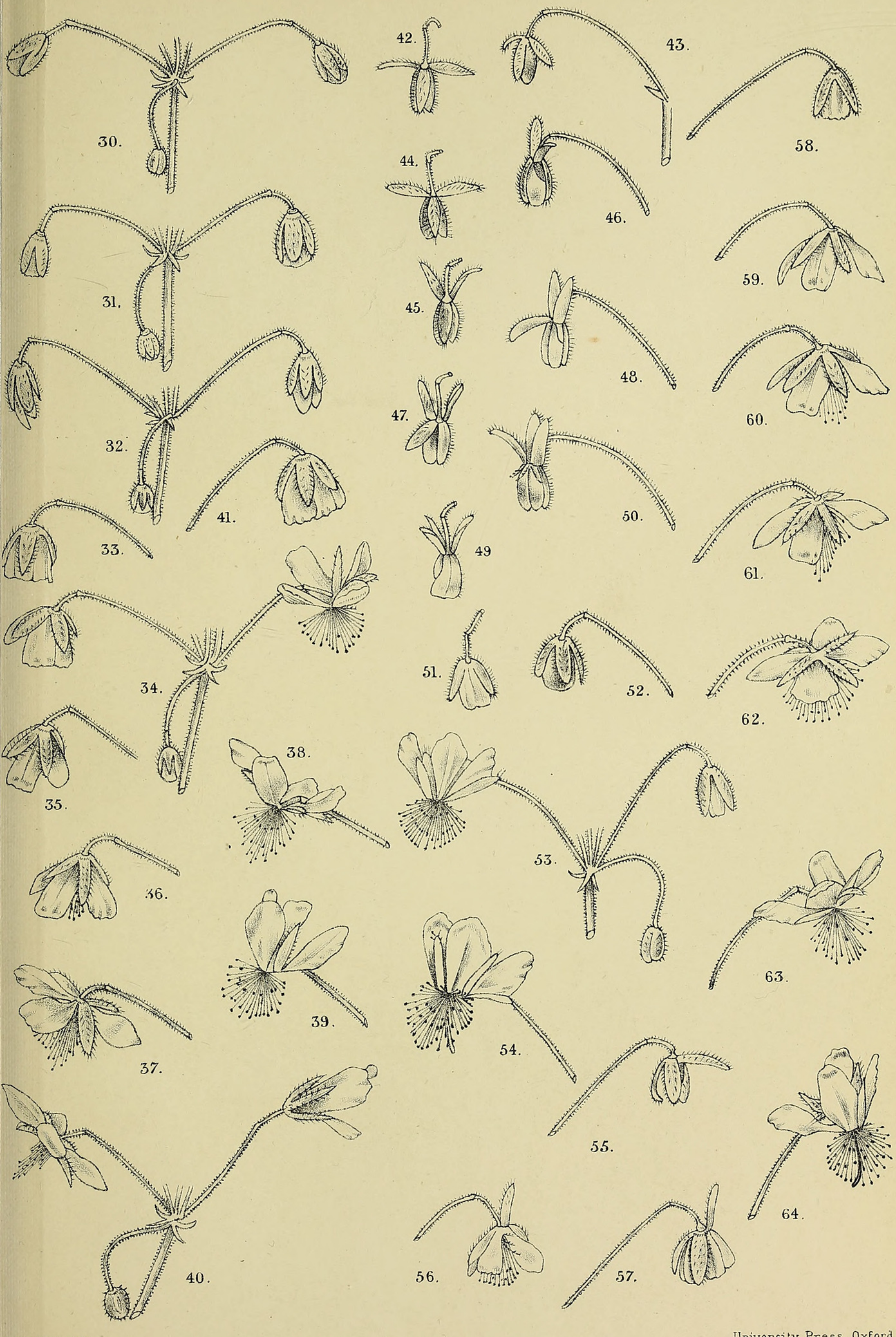

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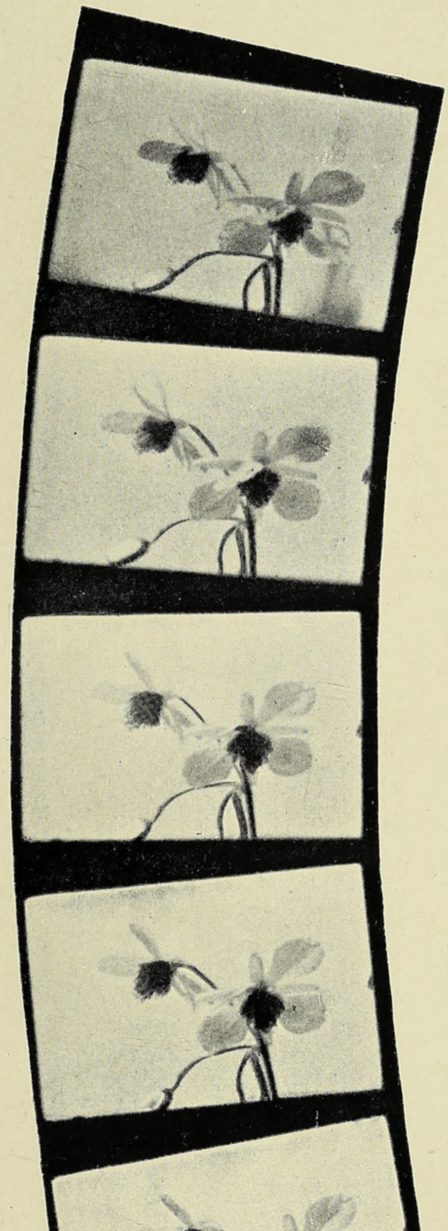

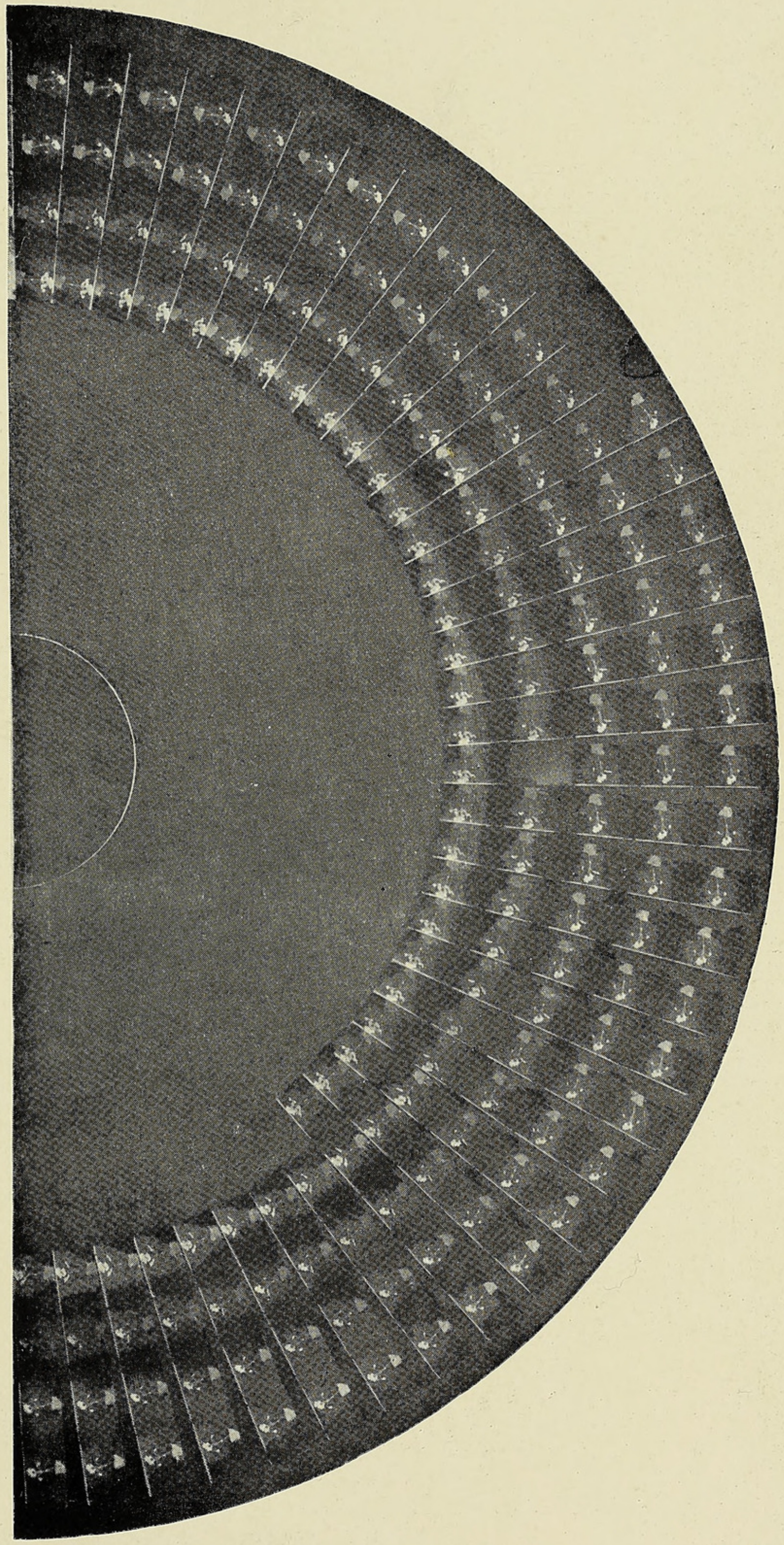

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