December 1919. Botanical Series. Vol. X, No. 5.

Memoirs of the Department of Agriculture

 in India

STUDIES IN THE POLLINATION OF INDIAN CROPS. I

BY

ALBERT HOWARD, C.I.E., M.A

Imperial Economic Botanist

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AGRICULTURAL RESEARCH INSTITUTE, PUSA

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I. Introduction.

The methods of pollination and the occurrence of cross-fertilization are matters of the first importance in the improvement of crops in India. On accurate information on these subjects depends the choice of the methods of improvement to be adopted, the testing of the new varieties obtained as well as the growth and distribution of seed to cultivators. The earlier results obtained in this direction at Pusa were published towards the end of 1910 in a paper entitled *The economic significance of natural cross-fertilization in India*[1] which dealt more with the occurrence of natural crossing in the field than with the detailed study of the flower and of its pollination. Since that time, the work has been continued in much greater detail and a number of other crops have been investigated. The facts connected with the flowering, pollination and fertilization of gram (*Cicer arietinum* L.), safflower (*Carthamus tinctorius* L.), and Indian mustard (*Brassica juncea* H. f. & T.), were incorporated in papers dealing with the general botany of these crops published in

[1] *Mem. of the Dept. of Agr. in India* (*Botanical Series*), vol. III, 1910, p. 281

1915.[1] Some of the information relating to Java indigo was published in 1916.[2] The present paper deals with the results obtained, up to the end of the *rabi* harvest of 1919, on the following crops:—San-hemp (*Crotalaria juncea* L.), pigeon pea (*Cajanus indicus* L.), Java indigo (*Indigofera arrecta* Hochst.), Sumatrana indigo (*Indigofera Sumatrana* Gaertn.), linseed (*Linum usitatissimum* L.), *taramira* (*Eruca sativa* Lam.), *til* (*Sesamum indicum* L.), *niger* (*Guizotia abyssinica* Cass.), jute (*Corchorus capsularis* L., and *C. olitorius* L.) and roselle (*Hibiscus Sabdariffa* L.).

The bearing of pollination studies on such subjects as the methods of improvement of crops, the introduction of exotics, the maintenance of types and the distribution of pure seed to cultivators, has already been discussed in two papers[3] (published in 1910 and 1912) largely from the point of view of the application or otherwise of the methods of pure line selection. Some of the results described in the present paper, for example, those dealing with the pigeon pea, indigo, and san-hemp, bring out other aspects of plant improvement which are not without interest at the present time.

In the pigeon pea, a crop widely grown and of great value in the rural economy of the country, yield is of far greater importance than quality. The problem before the breeder is to secure the heaviest crop possible. In carrying this out, the facts dealing with pollination and fertilization show that other factors, besides potential yielding power, are involved. Fertilization depends on atmospheric conditions and practically no setting takes place during damp, dull weather although self-pollinated flowers may be produced in profusion. This adverse factor can be avoided by increasing the range of the flowering period. This can be achieved most easily by the growth of a mixture of individuals differing considerably in time of flowering. In this way the risk is distributed and the yield is insured. This, however, involves the rejection of the method of pure line selection and the adoption in its place of mass selection in which crossing within certain limits is permitted.

In Java indigo the case is still more interesting. The crop consists of a mass of freely crossing heterozygotes with a wide range in general habit, root development, time of flowering and in the extent of leaf surface. Practically no setting takes place if insect visitors are excluded. The seed produced by artificial self-pollination is small in amount and gives rise to progeny of less

[1] *Mem. of the Dept. of Agr. in India* (*Botanical Series*), vol. VII, nos. 6 & 7, 1915, pp. 213 & 237.

[2] *Bulletin No. 67, Agr. Research Inst. Pusa*, 1916, p. 23.

[3] *Mem. Dept. of Agr. in India* (*Botanical Series*), vol. III, no. 6, 1910, and *Agr. Jour. of India*, vol. VII, 1912, p. 167.

vigour than that obtained when free flowering is permitted. These facts to all intents and purposes exclude methods of improvement based on the isolation of pure lines. There has been so much crossing in the past and the gametic constitution of each individual is so complex that many years' work would be necessary for the isolation of the unit species which underlie, as it were, the existing fabric of heterozygotes. Time is not the only factor involved in this unravelling. The crop is to some extent self-sterile and the plants raised from self-fertilized seed show, in a single generation, a considerable falling off in vigour. The isolation of pure lines in such a crop involves continuous self-fertilization for many years which would be certain to have its effect on the vigour of the culture. If the operation of this factor did not eliminate the selections altogether, it would be certain to lower their vitality to such an extent that the pure lines finally obtained would be worthless for any agricultural purpose. Methods of continuous mass selection, on the other hand, which were successfully adopted by the Dutch planters in Java when this crop was cultivated in that country, are far more promising. No attempt is made to prevent crossing but it is regulated and only permitted to occur between those individuals which are agriculturally desirable.

Cross-fertilization in the field is not the only way in which pure cultures can be contaminated. This can be brought about by the infection of the soil by self-sown seed of previous cultures of the same crop. The danger is specially important when hard seeds are produced and when the seeds possess the property of lying dormant in the soil in a viable condition for many years. One obvious method of avoiding the difficulty is the possession of a number of separate plots combined with a system of rotation. This suffices in all ordinary cases. In crops like roselle, Java indigo and Indian mustard, however, this is not sufficient. Dormant and hard seeds are brought up by the plough every year and self-sown seedlings of these crops have been known to appear in the plots of the Botanical Area at Pusa five years after the removal of the last culture. In addition to rotations and clean cultivation, two other methods are employed at Pusa to avoid contamination in such cases. After the removal of the culture, the plot is left uncultivated for a time so that the seeds left on the surface may dry thoroughly so as to increase their germination capacity. The land is then lightly cultivated after rain or irrigation when vast numbers of seedlings appear which are easily destroyed by a further cultivation. This process is repeated when possible. Afterwards the land is ploughed in the ordinary course. In this way, most of the seeds are destroyed and only a few are buried by the plough. In addition, such crops are always grown either in lines or transplanted from

seed boxes in lines at a definite distance between the plants. Provided all due care is taken and the cultures are kept under close observation, especially at the beginning, the danger of contamination through self-sown seed can be avoided altogether.

II. Some leguminous crops.

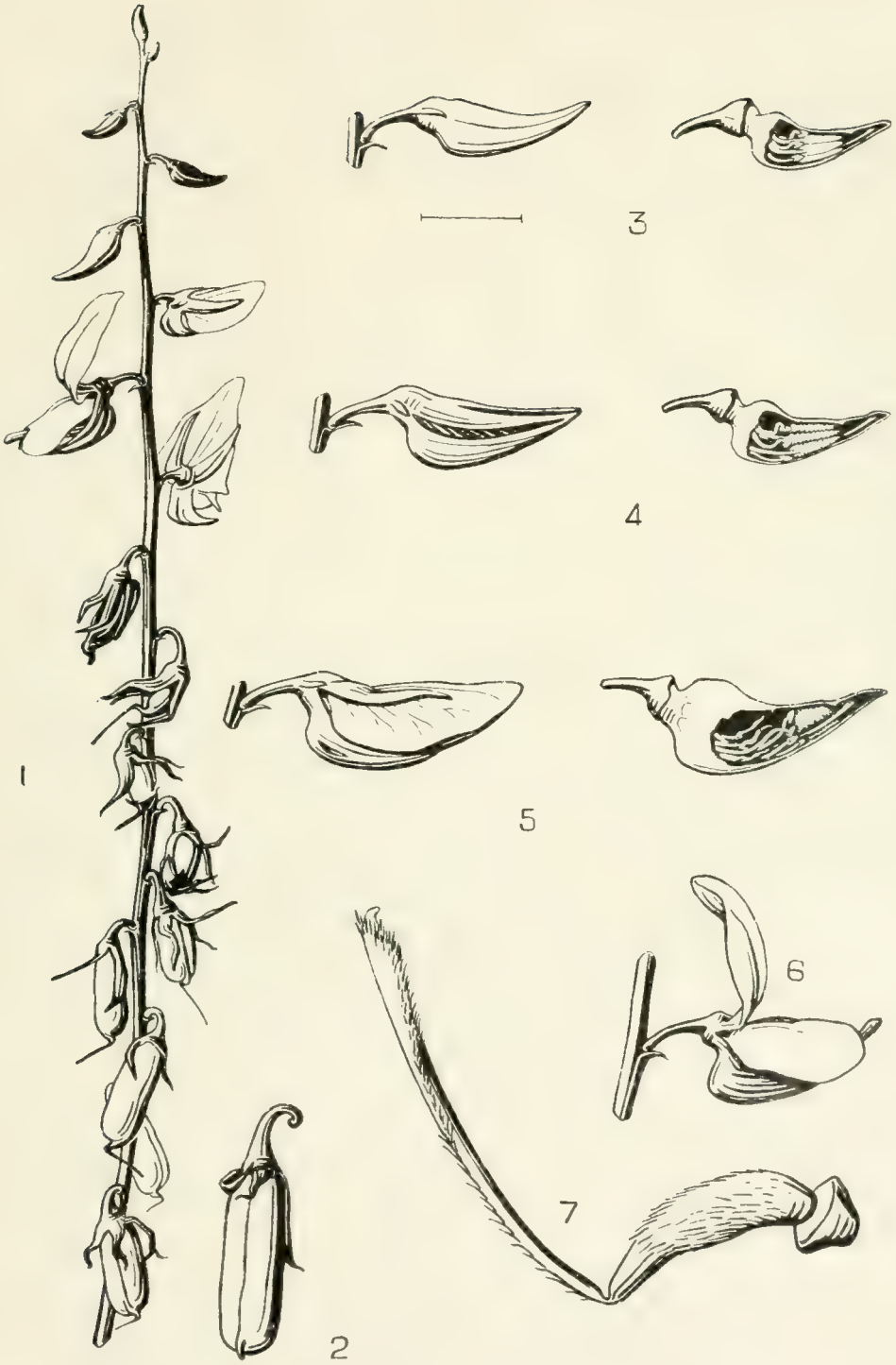
1. San-hemp.[1]

San-hemp (*Crotalaria juncea* L.) is widely cultivated all over India mainly for its fibre and as a green manure crop.

Flowering. The large conspicuous yellow flowers are borne on long terminal racemes, the first blossoms appearing when the plants have attained their full height (Plate I). The lowest flower of each inflorescence opens first and flowering proceeds regularly towards the growing point and is completed in the whole plant in about a month. The carina is very pointed, slightly twisted at the apex and closely shut. The stamens are diadelphous and unequal. The anthers of the shorter stamens are linear, of the longer ovate. Those buds which show slits in their calyces in the late afternoon with the yellow corolla showing through, open the following morning about 9 to 10 A.M. at which period the glands begin to secrete nectar freely. As a rule the flowers remain fully open for two days, partially closing at nightfall. Comparatively few of the flowers set seed under Pusa conditions.

Pollination. In the bud stage (Plate I) the two sets of anthers are in position at a considerable distance below the stigma. When slits appear in the calyx, dehiscence of the linear anthers begins and the filaments of the ovate set of anthers begin to increase in length and to press the liberated pollen towards the orifice of the carina. When the flower is fully open, the stigma (which is provided with a bunch of hairs round the stigmatic surface) lies towards the orifice of the keel and is free from the mass of pollen supported by the ovate anthers which have not yet burst. In addition to the bunch of hairs there is a line of hairs pointing upwards along the whole length of the style. These help to keep the pollen in position. When heavy insects like *Megachile anthracina* or *Xylocopa amethystina* alight on the wings and search for nectar, the piston mechanism is set in motion and first the stigma and then a pasty vermiculous mass of pollen are extruded and forced somewhat violently against the hairy abdomen of the insect. The flowers are also visited by *Megachile lanata* but this insect is too short for the stigma to strike its abdomen. It is however heavy enough to set the piston mechanism in motion and collects

[1] *Mem. Dept. of Agr. in India* (*Botanical Series*), III, 1910, p. 177 ; *Die Züchtung der landw Kulturpflanzen* Bd. V, 1912, s. 145.



POLLINATION MECHANISM OF CROTALARIA JUNCEA.

1, inflorescence. 2, a ripe pod. 3, a young bud. 4, a bud the evening before opening. 5, an opening bud. 6, an open flower. 7, the style showing the distribution of hairs.

pollen and in doing so is able to stimulate the stigmatic surface and to effect cross-pollination. The two small Indian bees, *Apis indica* and *A. florea*, visit the flowers for pollen left by the other insects but are not heavy enough to work the mechanism and therefore have no influence as pollinating agents. If the flowers are not visited by insects, the continued elongation of the filaments of the long stamens presses the pollen mass round the stigma. Both cross and self-pollination are therefore possible. The ovate anthers do not burst until their work of supporting the pollen mass in the carina is completed towards the end of the first day of opening or on the morning of the second. The arrangements for pollination therefore follow for the most part those described by H. Müller[1] in the case of *Lupinus luteus* L., but the piston mechanism is in *Crotalaria juncea* combined with the brush system of *Pisum sativum* L.

Fertilization. The arrangements at first sight suggest the possibility of self-pollination as well as cross-pollination but the former does not occur if the flowers are protected from insects. If flowering takes place in muslin cages, the pollen is liberated and forced all round the stigma in the usual manner but no subsequent setting takes place. The flowers last for four or five days and then gradually fade. If, however, a branch is led outside the net into the open air, setting takes place normally and pods and seeds form in the usual manner. These results suggest that the stigma must first be stimulated by contact with the insect before the pollen grains can germinate. To confirm this, some experiments were made in 1916 in which the stigmas were rubbed with rough cardboard before selfing. In all cases the experimental plants were covered with netting before flowering time and in two cases control inflorescences were allowed to flower freely outside. The results are given in the following table :—

Dates of rubbing and of self-pollination	No. of flowers treated	No. of pods produced	No. of pods which set seed	Total No. of seeds	
22nd October to 26th October	58	1	1	2	The free flowering branch formed 11 pods which gave 33 seeds.
22nd October to 26th October	65	15	13	73	The free flowering branch formed 13 pods which gave 38 seeds.
11th November to 17th November	103	49	40	..	No free flowering branch.

[1] H. Müller. *Fertilization of Flowers*, 1883, pp. 187 and 211.

These results prove that in this species as in many others of this order, autogamy does not occur unless the stigmatic surface is first stimulated. One consequence, therefore, of insect visitation is self-pollination. Stimulation of the stigmatic surface does not appear necessary however for cross-pollination. In 1916, a number of flowers were artificially crossed without first of all rubbing the stigma. All formed pods and set seed. These results indicate that cross-pollination by means of insects is the first object and that only if this fails is seed formation provided for by self-pollination.

Natural cross-fertilization. All the facts point to the possibility of extensive natural crossing in this crop. That this is so was confirmed by an experiment carried out at Pusa with two cultures of very different habit which were grown side by side and allowed to flower freely for some years. The morphological differences of these cultures are summed up in the table :—

	Local Pusa variety	Jubbulpore variety from the Central Provinces
1.	*Seed.* Small, shiny, black.	Large, dull black or greyish.
2.	*Seedlings.* Germination slow, small, with reddish downy cotyledonary leaves and stems.	Germination rapid. Seedlings large with green glabrous cotyledonary leaves and stems.
3.	*Plants.* Short, late maturing, with many flowered spreading branches beginning at a point about four feet from the ground.	Tall, early maturing, with a few short sparsely flowered parallel branches beginning at a point about eight feet from the ground.

At first, the natural differences between these two kinds were maintained but they somewhat rapidly disappeared and in two or three years the cultures were indistinguishable. Crossing had evidently taken place in all directions and eliminated the well marked differences in habit.

This result led to a detailed examination of the local Bihar crop in order to determine its constitution. The greatest amount of variation was noted in the standard of which twelve distinct types could be distinguished, differing in the colouration of the veins, in the depth of yellow and in the amount and distribution of a reddish tinge existing with the yellow. Several colour factors therefore occur in the flower and there is little doubt that the crop contains numerous forms differing very slightly from one another.

Improvement. The fact that no setting takes place if the flowers are protected, that seed formation is dependent on insect visits and that extensive natural crossing takes place render the improvement of this crop a difficult matter. Variety trials, extending over several years, are only possible by

the use of fresh seed for each set of sowings. Seed distribution to be successful would involve the production of enormous volumes of seed and arrangements for complete substitution of the existing crop over a large area. Anything less than this would rapidly be destroyed by vicinism. It is doubtful whether the improvement possible would repay the cost and trouble involved.

2. Pigeon pea.

The pigeon pea (*Cajanus indicus* Spreng.) is widely cultivated in most parts of India. Two varieties are referred to in the Indian literature on this crop—(1) var. *florus*, known as *tur* (early maturing with a dwarf habit), found largely in the Central Provinces and in Central India, and (2) var. *bicolor*, known as *arhar* (late maturing with a tall habit), cultivated in the plains. The crop prefers a light, moist soil with good natural surface drainage. Its principal enemy is frost, a danger which limits its cultivation in the colder regions of North-West India. *Arhar* is perhaps the most valuable restorative crop grown in India. By means of its deep penetrating roots, the sub-soil is broken up and aerated while by the fall of its leaves and flowers a considerable amount of organic matter is added to the soil. For these reasons, the crops which follow *arhar* as a rule give yields above the average. The flowers are papilionaceous and are borne in loose corymbose racemes sometimes forming a terminal panicle. They open at any time of the day from 9 A.M. to 5 P.M. and remain open for about a day and a half.

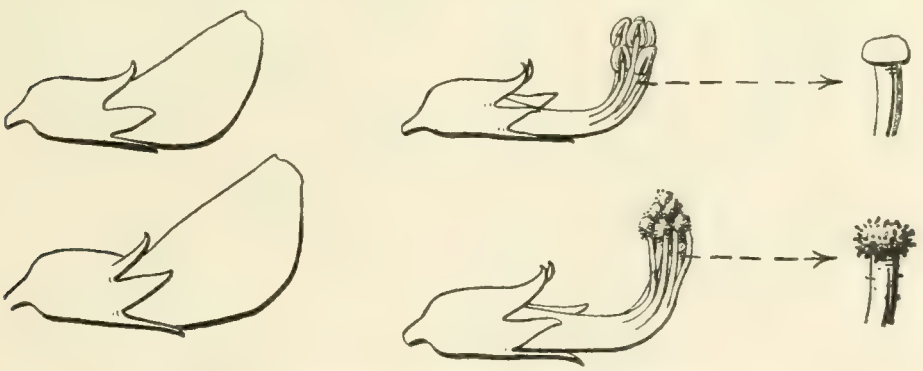


FIG. 1. Pollination of *Cajanus indicus* in the bud.

Pollination. In the bud stage, the anthers surround the stigma and burst the day before the flower opens and a dense mass of pollen is distributed all over the stigmatic surface (Fig. 1). In dry sunny weather, this pollen mass is partly removed by the action of wind and by the bees which visit the

flowers in large numbers. If, however, the weather is damp, the pollen masses decompose into a gelatinous substance, fertilization does not take place and the flowers fall.

Fertilization. This crop is characterized by the great extent of its flowering period and by the enormous number of flowers it produces. All are self-pollinated before the flowers open but the great majority fall without setting any seed. The expenditure of energy in flower formation is extraordinary. Setting depends on the humidity of the air. Dry bright days favour fertilization while dull damp weather causes the pollen grains to disintegrate and the flowers to fall without forming seed. Under dry bright conditions setting takes place freely under nets when insect visitors are excluded, thereby proving that self-fertilization readily takes place. The fact that the flowers are constantly visited by bees suggests that cross-fertilization is also possible.

Natural cross-fertilization. A considerable amount of work has been carried out at Pusa on the occurrence of natural cross-fertilization in this crop. In 1909, samples of *arhar* seed were collected from Bihar, the United Provinces, the Central Provinces and Bombay. The following year, 68 single plants were selected and the seed of each was sown separately. Of these, 61 gave rise to obviously mixed offspring while 7 (belonging to Bihar) appeared to breed true. In 1911, a further selection of 72 single plants was made of which 26 were obtained from cultivators' fields in the neighbourhood of Pusa. These were sown separately and definite splitting was observed in 65 of these cultures in the following respects—habit, time of flowering, colour of flowers (pale yellow, yellow, deep yellow, orange yellow, orange, reddish orange and all kinds of intermediate tints), colour and shape of the pods and seeds. In 1914, another set of 41 different plants was selected on the Dholi Estate. Twenty-three of these cultures did not breed true. The above results prove that natural crossing is common in the pigeon pea. As the self-pollinated flowers are largely visited by bees, it is probable that these insects are mainly involved.

To determine the precise extent of natural crossing, some observations were made in 1912-13 on a pure culture of *arhar* (characterized by pale yellow flowers and white seed) grown on a plot about half an acre in size next to a similar area of the ordinary local crop. The colour of the flowers and seeds of this pure culture made the detection of heterozygotes an easy matter. One hundred and forty single plants which were true to flower and seed colour were selected and sown separately the following year. Natural crossing was found to have occurred in 91 of the cultures (40 as regards flower colour and 41 as regards seed colour), that is, in 65 per cent. An exact count of the number

NATURAL CROSS-FERTILIZATION IN THE PIGEON PEA.

of crossed plants as regards flower colour was made in 40 of these cultures in each of which there was an average of sixty plants. Thirty cultures had only one stray plant each, seven had two plants, two had three plants and one had four plants—altogether 54 heterozygotes as regards flower colour among 2,400 plants, or 2·25 per cent. Through an oversight, similar counts as regards seed characters were not carried out. Grown in single lines next to next, the percentage of natural crossing is much larger. In an actual case it was found to be (as regards flower colour only) 578 in a total of 4,838 plants, or 12 per cent.

The characters which best lend themselves to the detection of heterozygotes and which show the kind of splitting which takes place in this crop are the general colour and markings of the standard, the colour of the pod and the characters of the seed coat. A number of careful observations have been made on these matters which are worthy of record.

As regards splitting in the general colour of the flower and in the markings of the back of the standard, the following three cases may be quoted :—

1. A parent plant with orange flowers (the back of the standard with many red lines and a diffused reddish colour) gave rise the next year to 64 plants which were grouped as follows (Plate II) :—

(*a*) *Flowers pale yellow.*

		Plants
Back of the standard	Without lines	2
	With a few red lines	4
	With red lines	2
	With many red lines	2

(*b*) *Flowers deep yellow.*

Back of the standard	Without lines	6
	With a few red lines	2
	With many red lines	4

(*c*) *Flowers orange.*

Back of the standard	Without lines	9
	With red lines	13
	With many red lines	12
	With many red lines and more diffused red colour	8

2. A parent plant with orange flowers (the back of the standard having red lines and a diffused red colour) gave rise the next year to 47 plants with yellow or orange flowers, differing however as regards the markings on the back of the standard as follows :—

	Plants
Uniformly deep red	24
Orange without red lines	4
Reddish orange without red lines	12
Yellow orange with red lines	7

3. A parent plant with yellow flowers (the back of the standard yellow with very faint red lines) gave rise the next year to 52 plants as follows :—

(*a*) Flowers orange, the back of the standard with red lines and diffused red colour .. 1 plant.

(*b*) Flowers yellow, the back of the standard without or with very faint red lines .. 25 plants.

(*c*) Flowers yellow, the back of the standard with many red lines but without any diffused red colour .. .. 26 plants.

The pods may be green or variously marked with red or black, the black markings being sometimes present to such an extent that the pod appears to be entirely black. The following three cases illustrate the splitting which occurs in the colour and markings of the pods :—

Parent	Progeny		Total number of plants
Pods with reddish lines	Black or reddish lines ..	30	42
	Nearly black	1	
	Green without lines ..	11	
Pods green without lines	Green without lines ..	14	52
	Nearly black	22	
	With black lines ..	16	
Pods with red lines ..	Green without lines ..	10	40
	With reddish black lines ..	29	
	Pods reddish black ..	1	

The most important seed characters are those of the seed coat. The ground colour may be white, grey, brown, reddish brown, purple, smoky or black. In general, there are, in addition to this ground colour, brown, black, violet or red spots or patches. When the ground colour is white or grey, two coloured spots occur one on either side of the hilum. In many cases, the

hilum is surrounded by a coloured ring. There appears to be no obvious connection between the colour of the seeds and the colour of the flowers (Plate II). Plants having similar flowers differ as regards the colour of the seeds, while similar seeds produce a wide range of colour in the flowers. The following three cases illustrate the kind of splitting met with as regards the colour and markings of the seed coat :—

Parent	Progeny		Total number of plants
Seeds whitish with a violet tinge and violet spots.	White to brown with or without a brownish ring round the hilum	20	60
	Light brown	3	
	Brown with a deep brown ring round the hilum or deep brown patches ..	3	
	Red	3	
	Smoky black	1	
	Black	3	
	Violet	1	
	White to brown with a violet ring round the hilum and violet patches and spots ..	26	
Seeds smoky black with black marks.	Violet black	1	44
	Yellowish brown ..	14	
	Smoky without any marks ..	10	
	Smoky with black marks ..	19	
Seeds reddish black.	Black	3	33
	Reddish black with black spots	3	
	Nearly black with patches ..	2	
	Smoky red	4	
	Dark red	5	
	Brown with black spots ..	3	
	Dark brown	3	
	Brownish red	3	
	Yellowish	7	

Improvement. Yield is of far greater importance than quality in the pigeon pea. Moreover, fertilization is dependent on the weather. To ensure the crop therefore a fairly wide range of forms as regards time of flowering is almost certain to give better results than a pure culture. Some experiments have been made on this point at Pusa. In 1911-12, one of the most promising of the pure lines, characterized by pure white seed and a pale yellow standard, was compared with the local mixed crop with the following results :—

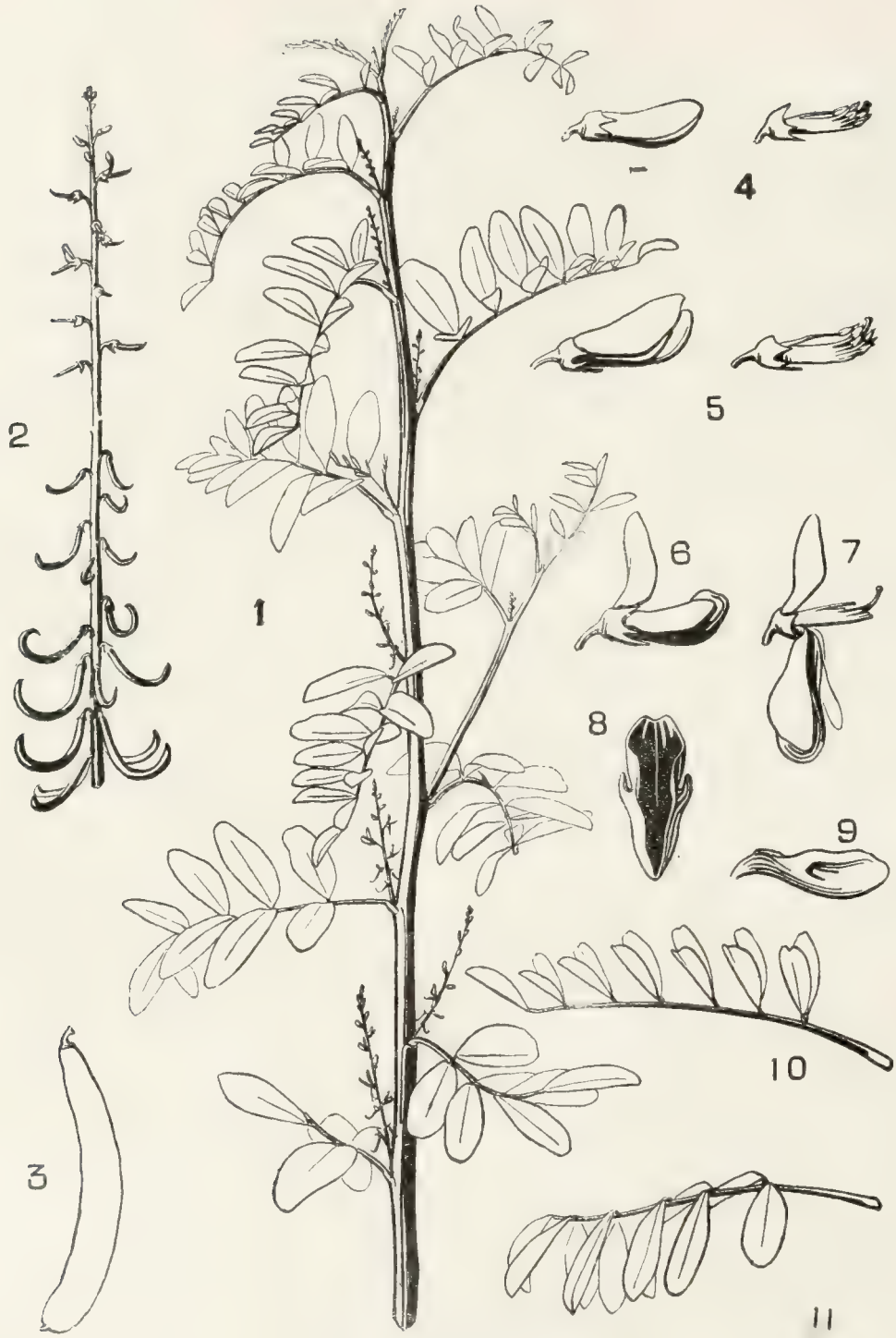
Variety	Area in acres	Actual outturn		Yield per acre	
		m.	s.	m.	s.
Pure line ..	0·5	5	6	10	12
Local crop ..	0·5	12	20	25	0

This result was not due to poor vegetative growth or lack of flowering on the part of the pure line but entirely to the better setting of the local crop, the flowering period of which was much greater than that of the pure culture. In the selection, out of a total of 4,838 plants, 578 plants split as regards flower colour. These two sets were threshed separately and the total weight of seed was determined. The results are given in the following table :—

Variety		No. of plants	Outturn in seers	Outturn per plant in seers
Selection	Homozygotes ..	4260	150	0·035
	Heterozygotes ..	578	56	0·097
Local crop		4784	500	0·105

The heterozygotes gave nearly three times the yield of the homozygotes. The next year, a comparison was made between the product of these heterozygotes and the local crop. The results were as follows :—

Variety	Area in acres	Actual outturn		Outturn per acre	
		m.	s.	m.	s.
Heterozygotes	0·58	6	18	11	5
Local crop	0·53	8	30	16	20



SUMATRANA INDIGO.

1, a flowering branch. 2, an inflorescence. 3, a ripe pod. 4, a bud. 5, an opening bud. 6, a flower just before an insect visit. 7, a sprung flower 8, the carina seen from above. 9, side view of the carina. 10, the position of the leaflets at midday. 11, the night position.

These results of course do not prove that pure line selection in this crop will never, under any circumstances, lead to improvement. They indicate however that the method will be attended with very considerable difficulties. Continuous mass selection by the elimination of unthrifty plants will probably give the best results.

3. Java Indigo.

The details relating to the flowering, pollination and to the occurrence of natural cross-fertilization in Java indigo (*Indigofera arrecta* Hochst.) were described and figured in 1915 in Bulletin No. 51 of the Agricultural Research Institute, Pusa. The bearing of these facts on the improvement of this crop was dealt with in considerable detail in Bulletin No. 67 published in 1916. Very little self-fertilization takes place in the case of protected flowers, the visits of bees being necessary for seed formation. The crop is composed of a mass of heterozygotes, differing widely in habit, time of flowering, root range and amount of leaf surface. There is evidence for believing that self-sterility occurs to some extent as there is a great falling off in vigour observable in the plants raised from self-fertilized seed. These circumstances and the ease with which the land becomes contaminated with the seed of previous cultures will render the improvement of Java indigo by the methods of pure line selection a time-consuming and very difficult undertaking. As is well known, this crop produces hard seeds in abundance and at harvest time there is a considerable amount of loss through the explosion of the pods. These hard seeds germinate naturally a few at a time during the second half of the monsoon and readily contaminate any culture sown on the same land unless special precautions are taken.

4. Sumatrana Indigo.

The structure of the flower and the arrangements for pollination in the case of Sumatrana indigo (*Indigofera Sumatrana* Gaertn.) closely follow those of Java indigo. The anthers burst in the bud just before the flower opens in the early morning. The flowers are visited during the morning by bees (*Apis florea* and *A. indica*), and the well known phenomenon occurs of the upwards discharge of pollen brought about by the explosion of the flower (Plate III). On November 11th, 1915, observations beginning at 7-15 A.M. were made on two branches to determine the number of flowers which opened and which were sprung during the course of a day. By 9 A.M., 13 flowers were open of which 7 were sprung. At 5 P.M., the same day, a total of 32

flowers had opened since 7-15 A.M. of which 31 had been sprung. In the two succeeding days, 77 more flowers opened, all of which were sprung.

Practically no setting takes place under nets but seed is produced under these conditions if the flowers are artificially made to explode. The amount of setting however is less than that obtained in the case of free-flowering plants visited by bees.

Attempts to cross Java and Sumatrana indigo at Pusa have so far failed. On several occasions, plots of these two crops have been allowed to flower side by side in October and November but no natural crosses have been observed in succeeding generations.

III. Oil seed crops.

1. Linseed.

The mode of pollination of the European cultivated forms of linseed (*Linum usitatissimum* L.) grown for fibre purposes has been described in detail by Fruwirth[1] who found that self-pollination is the rule and that good setting is obtained under bag without loss of vigour.

For some years, a large collection of pure lines of Indian linseed, obtained from the black soil areas of Peninsular India and also from the plains, have been under investigation at Pusa and observations have been made on the flowers of this crop. Indian linseed is cultivated for the oil in the seeds and is a short, much branched plant with thick stems and numerous capsules very different from the types grown for fibre in Europe (Plate IV).

Flowering. The flowers open in the early morning and as a general rule in all such buds, the folded corolla is visible the evening before. In rare cases, however, a flower opens in which the corolla is not visible the previous evening. As soon as the corolla becomes visible, the filaments are still short and the unburst anthers stand well below the slightly twisted stigmas. The rapid growth of the filaments, however, soon brings the anthers to the same level as the stigmas and this is the position when opening begins. The time of opening of the flowers depends chiefly on the temperature and humidity and to a less extent on the particular type. On warm mornings and when there is little or no dew, opening begins very early, while on cold dewy mornings the process is distinctly delayed. In February 1916, the following observations were made on this point :—

[1] Fruwirth. *Die Züchtung der landw. Kulturpflanzen*, Bd. III, 1906, s. 45.

INDIAN LINSEED.

1, a complete plant in flower. 2, a bud at 5 p. m. the day before opening. 3, an opening bud at 6-30 a. m. 4, a fully opened flower at 8 a. m. 5, self pollination at 9 a. m. 6, the style at 12 noon.

(1) February 9th. A cold day (max. temp. 70°F.; min. temp. 30°F.; temp. at 8 A.M. 47°F.).

No. of flower	Time of bursting of anthers	Time when opening of the flower was completed	Time of closing or falling of petals	Time of reopening of flower the following day
1	9–59	11–15	16–30	10–12
2	10–00	10–55	16–30	10–13
3	9–58	11–20	16–30	10–11
4	9–52	11–30	16–30	10–10
5	9–56	11–45	16–30	10–05
6	9–52	12–00	16–30	10–08
7	9–51	11–25	15–40	—
8	9–37	10–45	16–30	9–46
9	9–00	10–47	16–30	10–02
10	9–42	10–58	16–00	——
11	9–39	11–43	15–45	——
12	9–30	10–45	16–30	9–40

(2) February 6th. A warm day (max. temp. 86°F.; min. temp. 53°F.; temp. at 8 A.M. 61°F.).

No. of flower	Time of bursting of anthers	Time when opening of the flower was completed	Time of closing or falling of petals	Time of reopening of flower the following day
1	8–15	8–31	17–00	8–0
2	8–31	8–40	16–00	——
3	8–12	8–29	14–30	—
4	8–15	8–27	16–00	——
5	8–59	8–27	16–00	——
6	8–24	8–35	15–00	-
7	8–14	8–40	13–30	—
8	8–15	8–40	14–30	——
9	8–13	8–36	13–30	——
10	8–08	8–27	15–00	——
11	8–13	8–40	13–30	——
12	8–17	8–33	13–00	——

Thus the opening is not only delayed on cold days but flowers often reopen the following morning and the petals do not fall till the second day. On February 10th, 1916, a very warm day, some flowers began to show signs of opening as early as 3 A.M., while on February 9th, a cold day, opening did not begin till 7-30 A.M. As a rule on normal warm days, the flowers are fully open between 8-15 and 9 A.M. and from 10 A.M. to 12 noon on cold days. The petals begin to fall on the day of opening and this is generally completed by 5 P.M. A few, however, reopen the following morning and the number is considerably increased on cold and cloudy days.

Pollination. The anthers begin to burst longitudinally when the flower is half open and at this period they stand at a little distance from the crowded

stigmas and often at a slightly higher level. A few minutes later when the flower is fully open and the rupture of the anthers is complete, they close in on the stigmas and self-pollination takes place. Thus self-pollination takes place automatically by the help of the expansion of the corolla. At a little later stage, the burst anthers often fall together forming a cap over the stigmas—a movement which renders self-pollination a practical certainty. In many flowers it was observed that after the anthers begin to burst, twisting of the styles occurred which helped to move the burst anthers through 90° thus bringing their pollen-covered surfaces close to the stigmas. This twisting also brought the stigmas to a slightly lower level and so assisted the burst anthers to fall together and form a cap over the stigmas. In many cases the styles untwist after the anther cap is formed, a circumstance which still further favours self-pollination.

Cross-fertilization. Small bees visit the flowers for honey about 10 A.M. While collecting honey from the five nectaries, they occasionally come in contact with the burst anthers and with the stigmas so that cross-pollination is possible. That crossing may occasionally take place in India has been proved by a study of the cultures obtained from the seed of single plants. In 1916, the seed of 340 bagged plants was sown of which 334 bred true. Splitting took place in six cultures only—one gave rise to plants with different shades of blue flowers while five cultures produced plants differing in habit of growth. In 1917, the seed of 233 bagged plants was sown. All bred true except one which split as regards habit and flower colour. In 1918, the seed of 232 bagged plants was sown all of which bred true. All these observations indicate that in the field crossing is more frequent than would be suspected from a study of the flower. That this is so was confirmed by the results of sowing separately the unbagged seed of all the cultures raised in 1917. In these 233 cultures, stray plants were found in five cases as follows :—

No. 1 (white flowers). Two blue-flowered plants appeared which next year gave 84 blue and 32 white-flowered plants in one case and 129 blue and 34 white in the other, or a total of 213 blues to 66 whites.

No. 23 (white flowers). One blue-flowered plant occurred which gave next year 52 blue-flowered and 12 white-flowered plants.

No. 165 (white flowers). One blue-flowered plant was found which next year gave 84 blue-flowered to 19 white-flowered offspring.

No. 170 (pale blue flowers). One dark blue-flowered plant appeared which split as regards shape of petals, colour of pollen (white or yellow), and colour of petals—white and shades of blue from very pale to very dark blue. The ratio of total blues to whites was 264 : 7.

No. 217 (blue flowers). In this, three pale blues appeared which split next year into 8 blue and 342 pale blue, 4 blue and 133 pale blue and 4 blue and 278 pale blue.

A similar experience occurred in 1918. In 232 cultures from unbagged seed a total of 15 stray plants were found in nine of these cultures. In all probability many of these are natural crosses.

These examples are sufficient to show that natural crossing is more common in Indian linseed than would be supposed from a study of the flower. The cases are sufficiently numerous to make it clear that in exact work with this crop all seed must be raised under bag. This does not interfere with setting and as far as our observations go there is no falling off in vigour produced thereby.

2. Taramira or duan.

Taramira or *duan* (*Eruca sativa* Lam.) is a common cold weather oil seed crop in the drier areas of North-West India, where it is commonly grown mixed with gram or barley. The oil is used for lighting purposes and to a great extent as human food. The inflorescence is a corymbose raceme, the petals are greenish yellow with dark, often purple veins and the pods, which contain numerous light reddish brown seeds, are closely adpressed to the stem.

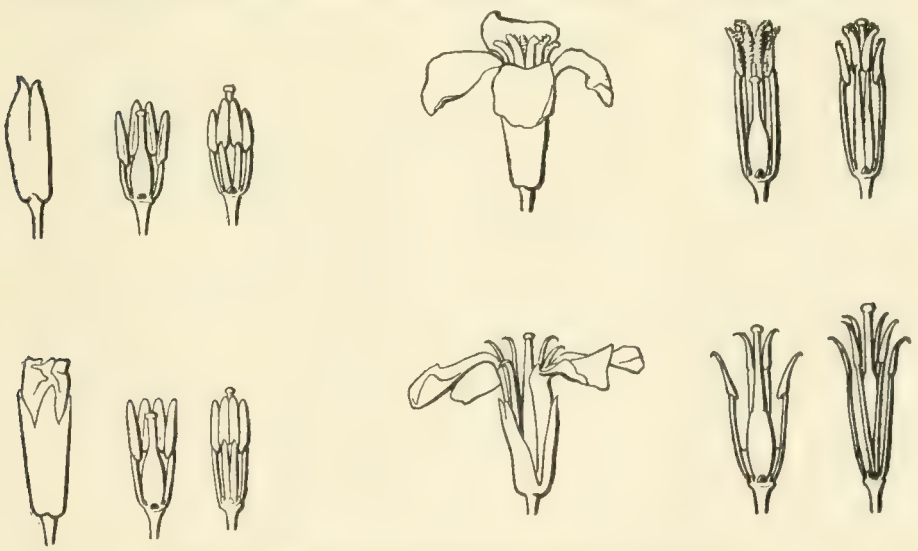


Fig. 2. Long and short styles in the flowers of *Eruca sativa*.

Pollination. The flowers open in the morning between 9 A.M. and 12 noon remaining open for about three days. Nectar begins to be secreted some time after opening takes place and is produced freely on the second and third days.

Generally two flowers on the same inflorescence open daily and as they last about three days it is usual to find six flowers open on the same branch. The anthers dehisce shortly after the flowers open and their pollen-covered surfaces are always turned towards the stigma. There are two types of flowers—long-styled and short-styled (Fig. 2). This difference in the length of the style can be distinguished in the bud stage and as the flower opens but it is most evident at the time the anthers burst. Afterwards it becomes lost as the flowers fade. Bees visit the flowers for honey up to the time the petals fall so that both self and cross-pollination are possible.

Fertilization. A considerable amount of work has been carried out on the fertilization of this plant. In 1909-10, fourteen samples of *taramira* from different parts of India where this crop is grown were sown at Pusa when it was observed that all the cultures were composed of a large number of very different types. Three hundred and thirty-four single plants were allowed to flower under bag but almost all failed to set seed—a very few seeds were found in only a few cases. A similar result was obtained the following year in the case of 402 plants. In 1911-12, a number of flowers were self-pollinated (either with pollen from flowers of the same inflorescence or from another inflorescence of the same plant) while others were cross-pollinated from different plants. In all cases the seed and pollen parents were bagged and every precaution was taken to avoid contamination with foreign pollen. The results are given in the following table :—

Flowers bagged and afterwards left untouched		Flowers selfed					
		Pollinated from flowers of the same inflorescence		Pollinated from flowers of another inflorescence on the same plant		Cross-pollinated from other plants	
Flowers treated	Pods formed	Flowers treated	Pods formed	Flowers treated	Pods formed	Flowers treated	Pods formed
79	0	18	1	42	6	24	24
		24	1	13	0	30	30
				20	0	13	13
				19	0	14	14
				16	0	18	17
				36	6	10	10
				22	4	10	10
				43	0	12	10
						34	34
79	0	42	2	211	16	165	162
		These 18 pods as a rule contained only one seed each.				Pods well filled with seed.	

The following year the selfed and crossed seeds in the above experiments were sown side by side. Only two of the selfed seeds germinated and the plants so produced were shorter and less vigorous than those raised from the crossed seeds. These results show that self-fertilization is exceedingly rare in this crop and that practically all setting is a result of cross-fertilization. The crop is, in consequence, a mass of freely crossing heterozygotes. It is possible that the self-sterility met with is a consequence of the existence of heterostyly. The self-sterility observed may turn out to be the consequence of illegitimate pollination. This was confirmed by the results of some preliminary experiments carried out at Quetta in 1919. When long and short styled plants were crossed, the flowers set seed freely.

3. Til.[1]

Til (*Sesamum indicum* L.) is the source of most of the sweet oil used in India where it is grown as a summer crop in the colder regions and as an autumn or winter crop in the warmer tracts. *Til* prefers a light soil and is usually grown as a mixed crop.

Flowering. As the various forms of cultivated *til* vary very greatly in habit, time of flowering and in growth period, it is only possible to give a general idea of the conditions under which flowering takes place. The flowers are borne in racemes, either singly or in twos and threes in the axils of the upper leaves and possess very short pedicels (Fig. 3.)

Both the main stem and the side branches, which in some types are very numerous, bear flowers in acropetal succession. In the case of some early types observed at Pusa in 1911, the seeds were sown on May 5th and the first flowers appeared on June 16th when the plants were eighteen inches high. By the time flowering was completed, the total height of the plants was $3\frac{1}{2}$ feet. Usually two flowers are open at the same time on any one inflorescence and in much-branched plants more than 20 flowers may be open at the same time. The plants are harvested before they are ripe to prevent the loss of seed by the splitting of the capsules.

Pollination and fertilization. The flowers open between 3-15 and 4 A.M. and fade soon after midday, the corolla being shed without closing between 3 and 4 in the afternoon. They thus remain open not more than 12 hours. In the bud before the flower opens, the four unripe anthers are below the stigma

[1] *Die Züchtung der landw. Kulturpflanzen*, Bd. V, 1912, s. 182.

which at this period is not receptive. The anthers begin to burst longitudinally after 4 A.M. and commence to liberate their pollen. At this time the two hairy lobes of the bifid stigma often begin to separate and become receptive. The position of the anthers and stigma at this period is as follows. The fork of the bifid stigma and the centre of the anthers of the two long stamens are at the

FIG. 3. A flowering branch of *Sesamum indicum*.

same level while the anthers of the two short stamens are at a lower level. Like other members of the order to which *til* belongs, the stigmas are irritable and the two lobes separate when touched. This causes one of the lobes of the stigma to move down between the two burst anthers of the long stamens.

TYPES OF COROLLA IN SESAMUM INDICUM.

PLATE V.

As all these organs are practically in contact, self-pollination is easy. By five in the morning, the stigma is generally covered with pollen and as insects are not observed till 6 A.M. a great deal of self-pollination is bound to take place. Very frequently, however, the anthers in some flowers do not develop but remain aborted and turn brown without shedding any pollen. In these cases the visits of bees easily bring about cross-pollination and it is probable that most of the cross-fertilization which takes place in this crop is due to this cause. Setting readily takes place under muslin and the seed so produced develops normally. In 1910, the seeds of a large number of single plants of *til* were sown separately at Pusa and the progeny examined. There was no doubt that many of these were heterozygotes and that natural crossing in this crop is considerable.

Varietal characters.

During the years 1909 and 1910, a good many sowings of *til* were made at Pusa, the seed in the first instance being that usually grown by the people in the various parts of India. From the 1909 crop, the seed of single plants, both free flowering and bagged, was saved in a large number of cases for sowing the next year. These cultures have enabled a preliminary study of this crop to be made. While many of the single plant cultures showed that they were raised from heterozygotes, nevertheless some bred true and from these it was observed that the Indian types of *til* differ in the following characters :—

1. *Colour of seeds.* The full development of the colour of the seed coat appears to be a question of development. White and brownish seeds are met with on the same plant while with black seeds, smoky and dark brown individuals occur. Further investigation of this matter is desirable.

2. *Rough and smooth seeds.* As a rule, the surface of the seeds is smooth. In the cultures raised from some heterozygotic smooth parents, however, some plants with rough seeds were produced. No homozygotes with rough seeds were isolated.

3. *Colour of corolla.* Several different colour types are met with from almost pure white to deep violet. (Plate V.)

4. *Hairiness and smoothness of corolla and capsule.* Forms with numerous hairs as well as less hairy types occur.

5. *Number of flowers in the leaf axils.* At first sight it would appear that in all the varieties of *til* three flowers in each leaf axil would be usual. As a rule, however, only one flower is produced, the other two bud-like bodies

developing into extra floral nectaries. Sometimes, instead of one flower and two nectaries, three flowers are developed and in these types there is little or no branching. This pair of characters however is not always differentiated as some plants bear two or three flowers in each leaf axil at the tips of the branches only while on the rest of the plant there is only one in each axil.

6. *Divided and entire leaves.* As a rule the leaves of this crop are entire except when the vegetative vigour is great as happened in 1909 at Pusa. Most of the plants had divided leaves and very few entire-leaved plants were seen. In the following year, when the plants were sown later and the vegetative vigour was less, entire leaves were common. It would appear likely therefore that the form of the leaf depends on the conditions of growth and in any case further study of this leaf character is required before it can be used for breeding purposes.

7. *Branched and unbranched habit.* Those types with one flower in the axil are generally much branched while those with three flowers have few or no branches.

8. *Earliness and lateness.* There is a great range as regards this character. Some of the Indian forms are so late that they can hardly be grown at Pusa.

4. Niger.

Guizotia abyssinica Cass. is an important oil seed crop in Central and Southern India where it prefers a light sandy soil.

Pollination and fertilization. Examination of the capitulum shows that this plant falls into the sunflower group of the *Compositæ* and that the details relating to pollination are no exception to the general rule in this group. There is a marginal ray of 7 to 12 ligulate florets (female) surrounding a disc of 40 to 60 tubular hermaphrodite flowers. The flowering period of each capitulum extends from 7 to 8 days. The tubular flowers open in the early morning and liberate their pollen in the tube at the time of opening. The style emerges covered with pollen about noon, the stigmas separating and curling back to the staminal tube the same evening. Rarely do the stigmas in bending back touch the pollen on their own style, a circumstance which perhaps explains the failure of this crop to set seed readily under muslin. The self-fertilized seed formed under bag however germinates and develops normally. From the character of the flowering, cross-fertilization is generally to be expected but some self-fertilization is also likely.

Cross-fertilization. That cross-fertilization is common in this crop was proved in 1911 at Pusa by the examination of 29 cultures raised from the seed of single plants. Of these, 23 contained heterozygotes while the remaining six appeared to be uniform. Splitting took place in the following characters—time of maturity, colour of the stem (green, red and intermediate tints), habit (branching or erect), size and margin of the leaves, colour of the seeds and height of the plants.

IV. Crops grown for fibre.

1. Round podded Jute.[1]

The cultivation of *Corchorus capsularis* L., the principal source of the jute of commerce, is chiefly confined to the Districts of Bengal, which comprise the deltas of the Ganges and Brahmaputra. This species is distinguished from *C. olitorius* L., by its rounded fruits in which the seeds are not separated by transverse dissepiments. In vegetative characters and in general appearance, however, the two species are very similar to one another.

Flowering. The flowers are small and inconspicuous and arise both on the main stem and on the side branches. They occur in cymes on the stem opposite a leaf where a short peduncle arises. This branches into from three to six short pedicels, each bearing a single flower, which, as would be expected, open at different times. The flowering period depends on the earliness of the type. In sowings made at Pusa on February 13th, 1911, the first flowers appeared at the beginning of June and by the middle of July most of the red sorts were in flower. The flowering period lasts about six weeks after which no growth in length takes place.

Pollination and fertilization. A few flowers open about 8 A.M. but the majority open later between the hours of 9 and 10 A.M. The corolla closes between two and four in the afternoon, the flowers remaining open, on the average, not more than five hours. Next morning, the withered calyx, corolla, stamens and style are shed and the small fruits begin to develop. In the bud, the numerous 2-celled anthers are above the divided stigma. Both anther cells split longitudinally and liberate their pollen in the bud about an hour and a half before the flower opens. In the open flower, the anthers are still around and above the stigma and therefore the chances of cross-pollination appear to be small. Bees visit the flowers but not in large numbers. Bearing in mind

[1] *Die Züchtung der landw. Kulturpflanzen*, Bd. V, 1912.

the floral arrangements and also the moist atmospheric conditions which obtain in the jute tracts during the flowering time, self-pollination as a general rule is to be expected. The flowers set seed freely under nets and the seeds so produced germinate and develop normally.

Cross-fertilization. As a check on these observations, the seed of 46 single plants of various types of jute were collected in the autumn of 1910 and were sown separately during 1911 at Pusa. Thirty-eight of these cultures were uniform in all respects while eight showed the presence of heterozygotes. In one culture of 64 individuals, eleven plants with green stems and 53 plants with reddish stems occurred. In another culture in which all the plants had red stems, both light reds and dark reds occurred. In six other cultures plants with red and others with green petioles occurred.

Improvement. The prevalence of self-pollination and the comparative ease with which heterozygotes can be detected and removed before flowering takes place, render improvement by form-separation an easy matter. The distribution of improved types of seed presents no difficulties provided the bulk of seed is large enough for the systematic replacement of the country crop.

2. Long podded Jute.[1]

The cultivation of *Corchorus olitorius* L. for fibre is restricted to one portion of Bengal and is of importance only on high lying sandy loams in the Districts of Faridpur, Nadia, Hugli and Pabna. It is inferior as a source of jute and is hardly ever grown under the inundation indispensable to *C. capsularis* L. This species is much more branched than the forms of round podded jute and its fruits are long beaked pods in which the seeds are separated by transverse dissepiments. In other respects it greatly resembles *C. capsularis.*

Flowering. The small inconspicuous flowers are borne as simple cymes both on the main stem and on the side branches and occur two or three together with very short pedicels on a common short peduncle which arises on the stem opposite a foliage leaf. The lowest flower buds open first and flowering proceeds as the stem elongates, there being not more than two or three flowers open on each branch at the same time. The earliest formed flowers rapidly produce pods so that a single plant of this species carries ripe fruits below, while the upper portion of the stem is still growing in length and producing

[1] *Die Züchtung der landw. Kulturpflanzen*, Bd. V, 1912, s. 150.

buds and flowers. The flowering period varies from about a month in the early kinds to six weeks in the late types.

Pollination and fertilization. Some flowers begin to open early in the morning about 6 A.M. but generally this process begins at 7-30 A.M. and is completed an hour later. The flowers remain open for a short time only—not more than three hours as a rule—and begin to close at 11 A.M., the process being complete about noon. On the following morning, the withered calyx, corolla, and stamens as well as the style are shed. In the young bud, the much divided stigma is always above the unripe anthers and these relative positions are maintained till just before the flowers open. At this point, the filaments elongate rapidly and carry the very numerous bilobed anthers above and around the stigma. In those buds which open early, the anthers burst when the flower is half open, the stigma is then closely surrounded by a dense forest of bursting anthers and self-pollination ensues. In the case of buds, which open late, the anthers begin to burst before the flower opens and sometimes pollination takes place in the closed bud. These arrangements greatly favour self-fertilization and natural crossing is rare. No cases have been detected in the Botanical Area at Pusa. The fact that the cultivators in the District of Hugli grow two late varieties of the crop—one red-stemmed and the other green-stemmed—side by side and go to some pains to keep them separate points to the absence of extensive cross-pollination. Bees visit the flower sparingly when fully open. Setting takes place readily under nets and the seed so produced germinates and develops normally.

Improvement. The rarity of natural crossing and the fact that each plant produces a large quantity of seed will render improvement by selection and subsequent seed distribution easy matters. In view, however, of the small importance of *C. olitorius* in India compared with *C. capsularis* it is not likely that a large amount of work will be done on this crop in the near future.

3. Roselle.

The details relating to the pollination of *Hibiscus Sabdariffa* L. have already been described and figured in detail.[1] Self-pollination is the rule and setting takes place normally under nets without any loss of vigour. Up to 1911, no cases of natural crossing were detected at Pusa. Since that time, a considerable amount of work has been done on the inheritance of characters

[1] *Mem. of the Dept. of Agr. in India (Botanical Series)*, vol. III, 1910, p. 314, and vol. IV, 1911, p. 31.

in this crop and numerous cultures have been raised. A few cases of natural crossing have been observed due to the visits of humming birds. Although these cases are rare, it is desirable in exact work on this crop to raise all the seed for sowing under net.

QUETTA:
June 4th, 1919.