RESPONSE OF COTTON TO LEAF-CURL DISEASE

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With an Appendix on the Distribution of Cotton Virus and *Bemisia* in Africa

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Introduction

Leaf-curl disease is potentially the most serious disease of Egyptian cotton in the Sudan, and is only kept under control by the uprooting and burning of every plant in the 200,000 acres of cotton grown annually in the Gezira. Moreover, *bamia* (*Hibiscus esculentus*) suffers severely, so that control of the disease in cotton depends on an efficient dead season for this crop also. Other known host plants in the Sudan are *Hibiscus sabdariffa*, *H. cannabinus*, *Althaea rosea*, *Malvaviscus* sp., *Sida spinosa* and probably *S. cordifolia*. The disease is caused by a virus, and is transmitted by white fly (*Bemisia tabaci* Genn. syn. *B. gossypiperda*). Carry over is by ratoon cotton and by alternative hosts. (For a detailed account of present knowledge of the disease, see Tarr, 1949).

Not all cottons are susceptible, so that a permanent insurance against the disease is obtainable by breeding resistant varieties. The present survey of a wide range of cottons was undertaken to provide information on the distribution of resistance.

Experimental methods

Advantage was taken of the survey of blackarm resistance in the C.R.S. collection* (see Knight & Hutchinson, 1950) to study the response of the various types to leaf curl. In all, 671 strains were tested. It is not so easy to ensure a uniform infection with leaf curl as with blackarm. The latter is a bacterial disease, and the pathogen can be sprayed on to the plants as a suspension in water. The former is a virus, and the only known methods of

* The C.R.S. collection is the living collection of types of the world's cottons maintained by the Central Research Station of the Empire Cotton Growing Corporation. It is now located at Shambat in the northern Sudan.

transmission are by the natural vector, white fly, and budding or grafting. An attempt was made to promote a heavy infection by distributing throughout the experiment infected plants that had been carried over from the previous season as ratoons in buckets. Unfortunately, it was necessary to locate the experiment on the fringe of the desert to minimize the risk of spreading blackarm and leaf curl throughout the farm. Under these exposed conditions white fly did not multiply as had been hoped, and only about 70% of the plants in the susceptible Sakel controls contracted the disease, although under optimal conditions of spread 100% infection is the rule.

At the end of the season the whole of the experiment was cut back—a standard practice in leaf-curl work—and the reaction of the plants was judged by grading the leaf symptoms on secondary growth on a '0'–'4' scale. This scale is defined as follows:

'0' Complete absence of leaf curl.
'1' Small, scattered vein thickenings.
'2' Vein thickenings involving small groups of veins.
'3' Large groups of veins or all the veins involved.
'4' All the veins involved, and foliar outgrowths (i.e. enations) present.

Leaf symptoms are illustrated by Kirkpatrick (1931, Plate XVIII); his Fig. 1 represents a light grade '2' on the present scale, Fig. 3 is a heavy grade '3', and Fig. 2 is about grade '4'.

With incomplete infection, considerable variation in attack is common from place to place in the same field, and was, in fact, observed between different plots of the Sakel controls. Small differences between plots of the strains under test are therefore no indication of real differences in resistance. Nevertheless, the uniformity of behaviour in major groups shows that differences between groups may be regarded as real.

SURVEY OF RESISTANCE

It will be seen from the data summarized in Table 1 that the two Asiatic species, *Gossypium arboreum* and *G. herbaceum*, are effectively immune. Only ten plants out of 4280 examined showed symptoms of the disease, and in all cases the attack was mild. *G. hirsutum* and its vars. *punctatum* and *marie-galante* are highly resistant. About 5% of the plants were attacked, and the bulk of these showed grades '3'–'4' symptoms. A large proportion of the infected plants occurred in a relatively small number of strains. Though the variation between plots of controls was such that little confidence can be placed on individual results, it is likely that real differences in susceptibility exist. The distribution of these probable susceptibles was sporadic, and unrelated to either systematic position or geographical distribution.

In *G. barbadense*, the proportion of plants attacked was much higher. Little more than half escaped. Most of those attacked showed severe symptoms, and the proportion of diseased plants in grade '4' was higher than was observed in *G. hirsutum*. As in *G. hirsutum*, differences were observed between strains in the proportion of plants attacked, but unlike the data from strains of *G. hirsutum*, those from *G. barbadense* showed a definite geographical grouping. Those from western South America were, as a group, more susceptible than strains from other parts of the range (see Table 2). The experiment was not sufficiently precise to show up differences in resistance between individual strains, but it is known that considerable variation exists in the Egyptian and Sea Island groups (see

Table 1. *Leaf-curl attack in the cultivated cottons*

Species and variety	Leaf-curl grade: Observed '0'	'1'	'2'	'3'	'4'	Total	Percentage '0'	'1'	'2'	'3'	'4'	Total
G. arboreum	3794	3	5	—	—	3802	99·79	0·08	0·13	0·00	0·00	100·00
G. herbaceum	476	2	—	—	—	478	99·60	0·40	0·00	0·00	0·00	100·00
G. hirsutum (Upland)	5180	12	43	137	58	5430	95·40	0·22	0·79	2·52	1·07	100·00
var. *punctatum*	2109	4	13	86	25	2237	94·28	0·18	0·58	3·84	1·12	100·00
var. *marie-galante*	1237	1	5	43	16	1302	95·01	0·08	0·38	3·30	1·23	100·00
G. barbadense	1582	5	94	688	548	2917	54·23	0·17	3·22	23·59	18·78	99·99

Bailey (1932) and subsequent reports of the Cotton Breeding Section, Sudan Government).

Data are also given in Table 2 for the two control types, Domains Sakel and its derivative, BAR14/1. It will be seen that Domains Sakel was rather more susceptible than the general run of *barbadenses* (other than those from western South America). In this type, the synthesis of a blackarm-resistant Sakel was undertaken. In the course of the work, it proved possible to add leaf-curl resistance by mass selection. BAR14/1, BAR14/7 and BLR14/16 are three successive stages in the development of this blackarm and leaf-curl resistant type. The first, BAR14/1, which was included in the main experiment, was appreciably more resistant than its Sakel parent. BAR14/7 was tested with Domains Sakel as a control in a subsequent experiment. In this trial over 99% of the plants in the control were affected, and three-quarters of them were of grade '3' or '4'. In BAR14/7 one-third of the plants remained free and only one in five reached grades '3' and '4'. BLR14/16 was tested against Domains Sakel at Shambat in the winter of 1948–9, and growth was not very vigorous. Hence the grade of leaf curl on the control was not as high as in the control for BAR14/7. Nevertheless, 98% of the control plants were attacked. In the resistant BLR14/16, only six plants out of 181 showed any sign of the disease (see Table 2). Similar results were obtained in the main-crop season in the Gezira. Evidently BLR14/16 is very highly resistant.

Table 2. *Leaf-curl attack in* Gossypium barbadense

Origin	Leaf-curl grade: Observed '0'	'1'	'2'	'3'	'4'	Total	Percentage '0'	'1'	'2'	'3'	'4'	Total
Main experiment:												
Western South America	151	—	19	231	190	591	25·55	0·00	3·21	39·09	32·15	100·00
Other *G. barbadense*	1431	5	75	457	358	2326	61·52	0·21	3·22	19·65	15·39	99·99
Domains Sakel controls	781	15	67	604	1038	2505	31·18	0·60	2·67	24·11	41·44	100·00
BAR14/1	492	6	26	315	455	1294	38·02	0·46	2·01	24·34	35·16	99·99
Subsidiary experiments:												
Domains Sakel controls	2	3	63	99	131	298	0·67	1·01	21·14	33·22	43·96	100·00
BAR14/7	92	65	67	38	23	285	32·28	22·81	23·51	13·33	8·07	100·00
Domains Sakel controls	2	39	19	26	2	88	2·27	44·32	21·59	29·55	2·27	100·00
BLR14/16	175	1	3	2	—	181	96·68	0·55	1·65	1·11	—	99·99

History of leaf curl and its spread in the Sudan

The earliest record of the disease was by Farquharson (1912) in Southern Nigeria, and he first used the name 'Leaf curl'. Jones & Mason (1926), working in the same area, described it as a virus disease. They examined herbarium specimens of the first diseased plants

observed in the Sudan (Lambert, 1924) and concluded that it was probably due to the same virus. They noted a range of symptoms, of which the following were the most important:

(1) Leaf curl: Upward curling of the margins of the leaf.

(2) Leaf-vein symptoms: In slightly affected leaves these consist of occasional minute intumescences on the smaller veins; as the attack develops, these spread, forming a regular thickening of the main and secondary veins. In severe cases foliar outgrowths develop, and these may attain a breadth of half a centimetre.

(3) Leaf mosaic: Leaf 'mottled to a chlorotic and dark green mosaic'.

(4) Bunchy top: 'The internodes are shortened, giving the plant a "bunchy-top" appearance. Affected leaves are greatly stunted and distorted by "blisters", while the colour is "savoyed" a light and dark green.'

Jones & Mason report that the first three types of symptom were common on affected plants of 'Native' (*G. barbadense*) cottons, whereas on American (*G. hirsutum*) the fourth syndrome was characteristic.

The first record of leaf curl in the Sudan was made by A. R. Lambert (1924), who recorded it as follows:

'"*Stenosis*" *in Cotton*

'A very small proportion of plants have been found in various parts of the Gezira showing stunted growth, the leaves and shoots curled and very much dwarfed, and the main stem often flattened and twisted. Specimens have been taken by the Government Botanist for examination and report. It does not appear to be of any importance at present, but should be kept under observation and any increase noted at once.'

Since affected plants were found 'in various parts of the Gezira', it is clear that this cannot have been the first occurrence of the disease. On the other hand, judging by its rate of spread in subsequent years, it cannot have been in the Gezira for many seasons before it was observed. The first published note of the disease was by Massey (1927) in a report on the 1926–7 season. He referred to it as 'leaf curl', and 'mentioned (it) for the sake of record', stating that 'the symptoms appear to be similar to those reported in Nigeria, but nothing is known of the causal factor'. Lambert (1928), reporting on the 1927–8 season, gives a description of the symptoms of leaf curl, and notes its marked spread (according to Bailey (1934) about half the plants in the Gezira were affected). At this stage only 'a very few plants have been noted each season badly affected'. 'At the time of writing, ratoon cotton in a Ratoon Experiment (both here and at Shambat) has come up with an even greater number of plants affected than in the past season.' This appears to be the first published record of the disease at Shambat, and suggests that it covered the 100 miles from the Gezira to Shambat in about four years. Massey & Andrews (1932) state that leaf curl was found in Tokar (some 400 miles from the Gezira) in 1929, and was 'prevalent in Sakel cotton in the Gash Delta' in 1931. It will be noted that until the 1927–8 season, the disease was not sufficiently prevalent to cause more than casual references in reports. In that year, according to Massey & Andrews, there was a serious infestation of white fly in the Gezira, and 50% of the plants were attacked by leaf curl. Bailey (1934) states that 'The next two seasons saw the completion of the process of penetration, and practically every cotton plant over the whole Gezira area—amounting to some 200,000 acres of cotton—showed more or less severe symptoms'. He records that the *bamia* crop developed the disease at about the same time as the commercial cotton crop.

Massey & Andrews (1932) record the receipt of 'a specimen of typically infected cotton from Wau in the Bahr el Ghazal in 1926'. Since they state that the diagnosis was not subsequently confirmed presumably the disease did not reappear in Wau. The next record of the disease in the south was by Knight (1934), who found it on *bamia* at Bor and Juba. He failed to find it elsewhere in Mongalla Province on *bamia*, and the Upland cotton crop was not attacked.

In Kordofan and the Nuba Mountains, Knight failed to find leaf curl in 1933, but in the following year F. W. Andrews found a plant of *Sida cordifolia** with typical symptoms of the disease, though it was not at that time present in the cotton crop. The first record of leaf curl on cotton (Upland) in the Nuba Mountains was made by R. R. Anson in about 1936.

Discussion

Relationship between the cotton viruses of West Africa and the Sudan

The similarity between the leaf-curl diseases of West Africa and the Sudan was first recognized by Jones & Mason (1926), and was accepted by workers in the Sudan (see Bailey, 1934), though it has never been possible to make comparative tests with living material. A very much wider range of symptoms is found in West Africa than occurs in the Sudan, so wide indeed as to suggest that the former is a centre of variability. Until the present experiment was carried out, this range of expression might have been attributed to the variability of the host material. In the Shambat experiment, however, a much wider range of host material was tested than is present in West Africa. All the plants recorded in Tables 1 and 2 as showing leaf curl exhibited the typical symptoms of Sudan leaf curl as seen on the Sakel controls. True leaf curl in the Sudan is, in fact, remarkably uniform. In addition to typical leaf curl, some plants in a few strains of *Gossypium hirsutum* (Upland) were attacked by a mild mosaic with symptoms similar to those described by Kirkpatrick (1931). Mosaic symptoms of a rather different kind (see Appendix) and true leaf-curl symptoms are frequently to be found on the same plant in Southern Nigeria. In the Shambat experiment, however, mosaic and leaf curl never occurred together, though they were occasionally to be found on different plants of the same strain. Kirkpatrick (1931) described his mosaic from Upland cotton varieties, notably Watts Long Staple, and he considered it merely the expression of the leaf-curl virus on Upland types. He gives an account of inoculation experiments in which the transference of infected white flies from leaf-curl Sakel to healthy Watts Long Staple was followed by the appearance of mosaic. Nevertheless, in retransmission experiments from Watts Long Staple to Sakel (using white fly) he failed to induce either leaf curl or mosaic symptoms. Since Upland cottons can get typical leaf curl, and Sakel does not develop leaf curl when inoculated with mosaic, the difference in symptoms cannot be regarded as simply a difference in host reaction. It seems more likely that two viruses are involved. If there are two viruses, or virus strains, in the Sudan, there are probably more in West Africa. Jones & Mason (1926) noted this possibility, but there appear to be no published reports of further work on the subject. Two observations made in West Africa in December 1947 are relevant, however. The improved Nigerian *barbadense* strain, Ishan A, was examined in the multiplication area at Meko, and 'bunchy-top' symptoms (*sensu strictu*, see Appendix) were found to be common. Typical leaf curl was also noted on a few plants. A plot of Ishan A grown at

* In this connexion it may be noted that R. E. Massey successfully transmitted leaf curl from cotton to *Sida spinosa*.

Tamale in the Gold Coast from Nigerian seed showed 100% 'bunchy top'. Since Ishan A has been shown to be resistant to ordinary leaf curl, both in Nigeria and the Sudan, there is a strong suggestion that 'bunchy top' may be a third strain of the virus. Observations which support this view are given in the Appendix.

Origin of leaf curl in the Sudan

There are two possible theories of the origin of Sudan leaf curl. One is that it arose in the Gezira *de novo*, and the other that it reached the Sudan from West Africa, where it is known to have existed for a much longer time. It has been suggested that virus diseases may arise as a result of metabolic disturbance in the host. For this reason, origin *de novo* cannot be dismissed as lightly as spontaneous generation in the ordinary sense. Although, in the nature of the case, it is impossible to disprove such an origin for Sudan leaf curl, nevertheless, while other possibilities remain, spontaneous origin can safely be discounted.

This leaves for discussion the possibility of a common origin with West African leaf curl, and the question of the route by which it reached the Gezira. Two alternatives exist, seed transmission, and spread through a chain of living hosts. Massey (1933) reports the results of extensive trials designed to detect seed transmission if it occurred, and among about 40,000 plants grown from seed from a heavily infected plot, no case of leaf curl was observed. Moreover, up to the time when leaf curl first appeared in the Gezira, there had been no importation of seed from West Africa. Arrival from West Africa in the seed can therefore be ruled out.

The opportunities for spread across central Africa on a chain of living hosts appear greater than might have been supposed. Gautier (1946) has drawn attention to the occurrence of cottons all along the invasion and slave routes between the Nile and the Gulf of Guinea, and though the common cotton to which he refers is an Asiatic, and presumably leaf-curl immune, he states that *barbadense* types are to be found in favourable places in French Equatorial Africa. *G. barbadense* also occurs sporadically across the northern parts of the Belgian Congo (Wouters, 1948). Broun & Massey (1929) record the occurrence of *G. barbadense* in the Zande country ('Nyam-Nyam') bordering French Equatorial Africa, and in the old Provinces of Bahr el Ghazal and Mongalla. Farther north, *punctatum* cottons which, though in general highly resistant, are not immune, occur commonly all the way from Northern Nigeria to Darfur, Kordofan, White Nile Province and, until recently, in Blue Nile Province. Moreover, *bamia*, which is very susceptible to leaf curl, is a native food crop cultivated in small, often isolated, patches throughout north central Africa, and is a wild plant in the drier northern belt of this area. *Hibiscus cannabinus* and *H. sabdariffa* are also susceptible and are found both cultivated and wild in the rain-fed areas of the Sudan. Leaf curl has been found on two species of *Sida*, which are common in short-grass country. Finally, in Nigeria, Jones & Mason (1926) noted leaf-curl and mosaic symptoms on *Urena lobata*, which is common across the heavier rainfall belt, and leaf-curl symptoms on *Triplochiton johnsonii*. Notes on the distribution of *Bemisia* spp. given in the Appendix show that there is a complete chain of potential vectors from West Africa to the Sudan. Possible links in the chain of spread of the disease are Massey & Andrews's (1932) record of leaf curl on a cotton plant from Wau in 1926, Knight's (1934) record of infected plots of *bamia* at Bor and Juba, and Andrews's report of infected *Sida cordifolia* in the Nuba Mountains in 1933.

The probable history of the spread of the disease from West Africa can now be recon-

structed. Occasional plants of cotton, *bamia* or other hosts were infected, but extensive spread was prevented by the isolation of the host plants. In this way a slow spread, as it were by stepping stones, took place, and recession in unfavourable years would have been prevented by survival on perennial hosts. Ultimately, the disease reached the areas of extensive agriculture on the banks of the Nile in the northern Sudan, and in 1923–4 gained a foothold in the great area of susceptible Egyptian cotton in the Gezira. About the same time it became epidemic on the *bamia* crops on the river banks (Bailey, 1934). These were of great importance for further spread, since *bamia* plots are almost contiguous in the riverain cultivations of the northern Sudan. Thus there was a direct line of spread down the river to the cotton at Shambat, which was reached in 1927–8, and southward up the Blue Nile and Rahad rivers and across to the Atbara and thence to the Gash and Baraka valleys, whence Tokar was reached in 1929, and the Gash about the same time.

Host-parasite relationship

Comparison of the data given in Table 1 with those for blackarm resistance in the world's cottons given by Knight & Hutchinson (1950) shows that the host-parasite relationship is very different in the two diseases. Knight & Hutchinson showed that blackarm originated in one of the primary centres of origin of the cottons. It attacks all members of the genus, and where resistance or immunity is now found they were able to trace it to development under the selective impact of the disease. Leaf curl, on the other hand, first appeared in an area to which the cottons were only recently introduced (Hutchinson, 1949) and can have had no selective impact on them except in West Africa and the Sudan. In spite of this, two of the four species of cultivated cottons are virtually immune, and a third is very highly resistant. This suggests that the pathogen is not very well adapted to cotton in general, and since it first attacked the genus in an area to which it had only recently been introduced, the possibility must be considered that it was originally a parasite of some other plant. A case of a mosaic disease of other plants attacking cotton was observed in Trinidad, where a mosaic attacks *Hibiscus esculentus*, *Sida* spp., and some other malvaceous weeds. In some seasons every plant of the various host species may be attacked, but in general cotton is entirely free. Dr S. C. Harland observed a single plant of *Gossypium klotzschianum* var. *davidsonii* on the Cotton Research Station that exhibited symptoms typical of this mosaic. He succeeded in transferring it to a New World cotton by grafting, but no further cases were observed for some years. Later, a careful search was made in Upland material on the Cotton Research Station, and over a period of 5 years about twenty cases of mild mosaic were noted. No evidence of spread in cotton was ever seen. It may be suggested that this is an extreme case of the situation under which leaf curl became established on cotton in West Africa. If the Trinidad mosaic had been slightly better suited to cotton, it might well have become established as a cotton disease.

Selection for resistance

Soon after leaf curl became serious in the Sudan, the existence of resistant *G. barbadense* strains was noted (Bailey, 1934). Breeding work was also undertaken in the susceptible commercial stocks. Lambert (1938) bred 'Lecrem' by selecting resistant plants in Domains Sakel, roguing their progenies heavily and bulking the seed from the survivors. Selection also yielded resistant lines in NT2, another Sakel type, and Evelyn bred resistant strains from both Massey's Sakel and Domains Sakel by a similar process. In all cases resistant

plants were selected in large populations suffering from a devastating attack of the disease, and the difference between the progenies of these original selections and the controls was often large. Further selection led to steady progress towards immunity.

In the BAR14 line (Table 2) a rather different process was followed. Here, the first improvement was obtained by selection in the Sakel parent used for backcrossing in a blackarm resistance transference programme. This meant that only a very modest selection pressure was exercised, since the population was small, and each year the parent was replaced by a fresh stock from the Gezira, which had not been selected for leaf-curl resistance. In the early generations, advances in leaf-curl resistance were small, as may be seen by comparing BAR14/1 with its Domains Sakel control in Table 2. A comparison of BAR14/7, which represents the product of two more backcrosses, with its Sakel control shows that in later generations progress was more rapid. Finally, by a single generation's selection in inbred BAR14/7, the very highly resistant BLR14/16 was produced.

From the nature of the response to selection it may be concluded that leaf-curl resistance in cotton is controlled by minor genes. This is in sharp contrast to the position with blackarm resistance, where Knight & Hutchinson (1950) have shown that effective resistance can only be built up around a major gene. It is suggested that leaf curl is not specific to cotton, and that even in susceptible varieties of this host, little change in the genotype is needed to give virtual immunity.

SUMMARY

Leaf curl is an extremely serious disease of Egyptian cotton and of *bamia* (*Hibiscus esculentus*) in the Sudan. A survey was made of the response to the disease of 671 strains of cotton. *Gossypium arboreum* and *G. herbaceum* are effectively immune, and *G. hirsutum* and its vars. *punctatum* and *marie-galante* highly resistant, but *G. barbadense* contains a large proportion of susceptible strains.

Evidence is presented for the belief that the disease reached the Sudan from West Africa through a chain of host plants across the north equatorial region, and that its spread within the Sudan from one major cotton area to another was in the main along the riverain crops of *bamia*.

The variability of leaf-curl symptoms in West Africa as compared with the Sudan indicates that several virus strains may be involved.

A large proportion of the cottons possess resistance that cannot have been developed under the selective impact of the disease, and it is shown that the breeding of resistant types has been accomplished repeatedly by the accumulation of minor genes by selection. It is suggested that leaf curl is not specific to cotton, and that even in susceptible varieties, little change in the genotype is needed to give virtual immunity.

APPENDIX

On the distribution of cotton virus and Bemisia *in Africa*

Whilst visiting the cotton-growing areas of West Africa between October 1947 and January 1948 notes were made on the symptoms and occurrence of disorders of the cotton plant which were suggestive of virus diseases, although it was not possible to prove that viruses were involved or to determine the vectors. Some reference has been made to these observations elsewhere (Hutchinson & Pearson, 1948*a*, *b*; Pearson, 1948); they are recorded

here more fully because they have a bearing on the subject of the main paper and in the hope that they will be followed up by other workers.

Three fairly distinct types of affection were seen, corresponding roughly with the conditions described by Jones & Mason (1926) as 'Bunchy Top', 'Mosaic' and 'Leaf Curl'. Jones & Mason's descriptions are not entirely satisfactory because the symptoms are not always found in the same combinations, or on the same kinds of cotton, as they describe them, and this is particularly the case in the Sudan. The names will be more useful, both for descriptive purposes and as a reflexion of the position in the field, if they are redefined as follows:

A. *Bunchy Top.* Characterized by a progressive reduction in the size of all foliar and floral parts, and of the internodes, accompanied by a clogging of the main veins of the leaf. The stipules remain normal in size. There is no mosaic or crinkling of the leaves. The disorder somewhat resembles that known as 'Psyllose' (Soyer, 1947), which occurs only in the Belgian Congo, but the symptoms are less striking and the reddish purple tinge of stems, petioles and leaves on plants affected by Psyllose is absent. The disorder may be that noted by Cotterell (1931) in Togoland as similar to the loggerhead of cotton described by Nowell (*Diseases of Crop Plants in the Lesser Antilles*), though the latter shows leaf mottling and not, apparently, a reduction in leaf size. The phrase 'Bunchy Top' has been used by Bedford (1938) to describe one of the conditions associated with the vague and ill-defined disorder known as 'Crazy Top' found in American cotton in the Northern Pump scheme areas of the Sudan. Bedford's description, however, includes no reference to clogging of the veins, and states that affected plants eventually revert to normal growth; this suggests a temporary physiological maladjustment. The phrase 'Bunchy Top' is used descriptively in this Appendix, and no homology is intended with any other condition called by this name in the literature, other than that mentioned by Jones & Mason (1926). Examples were seen as follows:

	On *G. barbadense*	On *G. hirsutum*
Nigeria	Nassarawa, Oke-Iho (on *peruvianum* type); Oyo, Ibadan-Ilugun, Meko (on Ishan A*)	Keffi (on Allen ex Zaria)
Gold Coast	Akrobi (Wenchi district); Tamale (on Ishan A from Ibadan)	
French Soudan	M'Pessoba (on plot labelled 'Ishan', often both plants in the same hole affected)	Koutiala (on N'Kouralla)
French Cameroons	—	Doumayo (on Upland × *punctatum*)
Oubangui Province, French Equatorial Africa	—	Station de l'Ouham (on Triumph var. Grimari 325; squares and flowers almost entirely shed, branches tend to ascend and twist somewhat)

B. *Mosaic.* Very fine mosaic pattern of dark and light green on leaves, usually with swelling and clogging of the subveins sometimes accompanied by leaf-like outgrowths. Some reduction of the leaves to single lobes and some suggestion of dwarfing, but no lengthening and twisting of internodes. Examples were seen as follows:

	On *G. barbadense*	On *G. hirsutum* var. *marie-galante*
Nigeria	Nassarawa, Oyo, Iseyin, Oke-Iho, Odo-Oda, Ogbomosho, Oshogbo and Okene (all on *peruvianum* type)	—
Gold Coast	—	Kpeve hill and Basa

* Ishan A is a selection from the *vitifolium* type of *G. barbadense*.

C. *Leaf curl.* At first the smaller veins become thickened on the lower surface of the leaf and appear clogged when viewed against the light; later, the main veins may be similarly affected. The thickening of the veins causes a crinkling of the leaf lamina, which becomes thickened and leathery, with the margins curled, usually upwards. In later stages leaf-like outgrowths develop, often cup-shaped and several millimetres in diameter, and typically on the main veins. The same symptoms occur on the extra-floral bracteoles. In extreme cases the internodes become lengthened, flattened, twisted and ascendant, the leaves are reduced in size and the flowerbuds shed. Typical Sudan leaf-curl symptoms as described above were seen, though not in their most extreme form, as follows:

	On G. barbadense
Nigeria	Moko (on Ishan A)
Ivory Coast	Bouaké (on Ishan A, imported from Nigeria in 1941 and since bulked)
Gold Coast	Chito and Kpevo hill (on *G. barbadense* type *vitifolium*)

In addition, a number of cases were seen which could not definitely be allocated to either the mosaic or Sudan leaf-curl type exclusively:

Nigeria	Ogbomosho, Ado-Ekiti, Ijan, Ubiaja, Akure, Idamre (all on *G. barbadense*, mainly *peruvianum* type), Ibadan-Ilugun (on abandoned Ishan A) Oyo (on *G. barbadense*, *peruvianum* type; leaves very small, thick, large outgrowths from main nerve, definite twisting of stem, very close to Sudan leaf curl but still distinct) Kungumagazi (between Kontagora and Birnin Kebbi), on *G. hirsutum* var. *punctatum* stand-over crop; leaf veins thickened below and clogged, no twisting of internodes; much white-fly
Gold Coast	Near Kete-Krachi (just west of River Volta) on *G. hirsutum* var. *marie-galante*; network of swollen subveins and small mottle of leaf

The affection described as 'Bunchy Top' above seemed quite easily distinguishable from the 'Mosaic' and 'Leaf Curl', because of the characteristic reduction in length of internodes, the absence of mosaic, of crinkling, and of foliar outgrowths, and the initial clogging of the main as distinct from the subveins of the leaf.

The difference between 'Mosaic' and 'Leaf Curl', on the other hand, is not at all clear-cut, and it was impossible to decide by field observation whether the former is an early stage of the latter, or whether two distinct diseases are concerned.

The mosaic effect is certainly much commoner on *G. barbadense* in West Africa than it is in the Sudan, and it always accompanied other symptoms of leaf curl in var. *marie-galante*. All the cases seen, however, were of a definite mottling* (the individual patches of contrasting colour being small), and nothing was seen resembling the so-called 'mosaic' described by Kirkpatrick (1931) from *G. hirsutum* in the Sudan, which is characterized by a *clearing* of the veins and tissues immediately adjacent to them.

Distribution of Bemisia *on cotton in Africa.* Leaf curl of cotton in the Sudan was proved to be transmitted by a white fly (Aleurodidae) identified as *Bemisia gossypiperda* M. & L. (Kirkpatrick, 1931). The leaf curl of cotton found in Nigeria was also proved to be transmitted by a white fly (Golding, 1930), subsequently described as *B. goldingi* n.sp. (Corbett, (1935) which has also been recorded from Uganda (Gwynn, 1940). *B. gossypiperda* M. & L. was originally described as a pest of cotton in the Punjab, though it was not associated there with any virus disease of cotton (Misra & Lamba, 1929). It was later synonymized

* This is presumably the condition referred to by Jones and Mason (1926) when they speak of the colour of leaves being 'savoyed' a light and dark green, an expression which shows some confusion between form and colour pattern.

with *B. tabaci* Gennadius (Takahashi, 1936) and under the one or the other name has been recorded from the following countries, in addition to the Sudan and India:

Marianna Islands, on cabbage (Takahashi, 1936); Formosa, on cotton (Takahashi, 1931); Sumatra, carrying tobacco pseudo-mosaic (van der Laan, 1940); Mauritius, on tobacco (Takahashi, 1940); Nyasaland, on cotton (Smee, in litt.); Kenya, on cotton (Le Pelley, in litt.); Belgian Congo, on cotton (Henrard, 1937); French West Africa, on cotton (Delattre, in litt.); Morocco, on cotton (Mimeur, 1946); Spain, on tobacco (Gómez-Menor, 1943); Italy and Sicily, on cotton (Russo, 1942).

Other records of Aleurodidae on cotton are of *B. hancocki* Corbett from Uganda (Gwynn, 1940), *B. inconspicua* Quaint. from the Philippines (Otanes & Butac, 1939), *B. rhodesiaensis* Corbett from Southern Rhodesia under the name tobacco whitefly (Mossop, 1932), *Bemisia* sp. (not identified) from Somalia (Paoli, 1931), Iraq (Guest, 1931) and Tanganyika Territory (Harris, 1934), and *B. gossypiperda* M. & L. var. *mosaicivectura* from the Belgian Congo (Mayné & Ghesquière, 1934). The last named is reported as transmitting a mosaic to cotton; apart from this, only the species of *Bemisia* associated with cotton in Nigeria and the Sudan are definitely known to carry virus diseases of cotton. In India, although *B. tabaci* Genn. is very abundant on cotton, cotton leaf-curl virus is unknown, although the same insect in India is a vector of tobacco leaf curl (Pruthi, 1939) and of a yellow-vein mosaic of *Hibiscus esculentus* (Anon. 1942).

Leaf curl of cotton has fortunately not so far reached Egypt, where the varieties grown are probably susceptible. The only reference in the literature is a statement by Balls (1934) that although there is in Egypt a white fly which carries a leaf curl to hollyhocks (*Althaea rosa*), the virus never infects cotton.

It will be seen that there is a sufficiently wide distribution of *Bemisia* associated with cotton in Africa to support the hypothesis suggested in the main paper that cotton leaf-curl virus has spread across Africa, although the taxonomic relationship and the ability to transmit leaf-curl virus of the *Bemisia* on cotton in the various countries needs critical examination.

REFERENCES

Anon. (1942). *Annual Report Imperial Council of Agricultural Research*, 1940–1. Delhi, 1942.

Bailey, M. A. (1932). *Reports received from Experiment Stations*, 1930–1, *Anglo-Egyptian Sudan*. London: Emp. Cott. Gr. Corp.

Bailey, M. A. (1934). Leaf curl disease of cotton in the Sudan. *Emp. Cott. Gr. Rev.* **11**, 280–8.

Balls, W. L. (1934). *Rep. 2nd Conf. Cott. Gr. Probl.* p. 11. London: Emp. Cott. Gr. Corp.

Bedford, H. W. (1938). *Ann. Rep. Agric. Res. Serv. Sudan* 1938, p. 66.

Broun, A. F. & Massey, R. E. (1929). *Flora of the Sudan*. Sudan Govt.

Corbett, G. H. (1935). On new Aleurodidae (Hem.). *Ann. Mag. nat. Hist.* (10), **16**, 240.

Cotterell, G. S. (1931). Unpubl. report, Dep. of Agric., Gold Coast.

Farquharson, C. O. (1912). Report of Mycologist. *Ann. Rep. Agric. Dep. Nigeria*.

Gautier, J. (1946). La culture du cotonnier en Afrique equatoriale française. *Rev. Int. Bot. appliquée et d'agric. trop.* Jan.-Feb. nos. 279–80, pp. 3–10.

Golding, F. D. (1930). A vector of leaf curl of cotton in Southern Nigeria. *Emp. Cott. Gr. Rev.* **7**, 120.

Gómez-Menor, J. (1943). Contribución al conocimiento de los Aleyródidos de España (Hem. Homop.) 1a Nota. *Eos*, **19**, 173.

Guest, E. (1931). *Mem. Dep. Agric. Iraq*, no. 15. Baghdad.

Gwynn, A. M. (1940). In *Agriculture in Uganda*. Oxford University Press.

Harris, W. V. (1934). *Rep. Dep. Agric. Tanganyika*, 1933, p. 69.

Henrard, P. (1937). Les insectes parasites du cotonnier dans la région de Lisala. *Bull. agric. Congo belge*, **28**, 609.

HUTCHINSON, J. B. (1949). The dissemination of cotton in Africa. *Emp. Cott. Gr. Rev.* **26**, 256.

HUTCHINSON, J. B. & PEARSON, E. O. (1948*a*). Report on a visit to Nigeria, Nov.–Dec. 1947 (unpublished).

HUTCHINSON, J. B. & PEARSON, E. O. (1948*b*). Report on a visit to the Gold Coast, Dec. 1947 (unpublished).

JONES, G. H. & MASON, T. G. (1926). On two obscure diseases of cotton. *Ann. Bot., Lond.*, **40**, 759–72.

KIRKPATRICK, T. W. (1931). Further studies on leaf curl of cotton in the Sudan. *Bull. ent. Res.* **22**, 323–63.

KNIGHT, R. L. (1933). A short report on experimental plots in Nuba Mountains, November 1933 (unpublished).

KNIGHT, R. L. (1934). A short report on experimental plots in Mongalla, December 1934 (unpublished).

KNIGHT, R. L. & HUTCHINSON, J. B. (1950). The evolution of blackarm resistance in cotton. *J. Genet.* **50**, 36–58.

LAMBERT, A. R. (1924). Gezira Research Farm: Botanical Section, Ann. Rep. 1923–4 (unpublished).

LAMBERT, A. R. (1928). Gezira Research Farm: Botanical Section. *Agric. Res. in the Sudan, Rep. Season* 1927–8, p. 62. Sudan Govt.

LAMBERT, A. R. (1938). New Sakel strains in the Anglo-Egyptian Sudan. *Emp. Cott. Gr. Rev.* **15**, 14–20.

MASSEY, R. E. (1927). Work of the Section of Plant Physiology and Pathology. *Agric. Res. in the Sudan, Rep. Season* 1926–7, p. 136. Sudan Govt.

MASSEY, R. E. (1933). Section of Botany and Plant Pathology. Final Report on Experimental Work in 1932–3. Ann. Rep. Gezira Agric. Res. Serv. p. 145 (unpublished).

MASSEY, R. E. & ANDREWS, F. W. (1932). The leaf curl disease of cotton in the Sudan. *Emp. Cott. Gr. Rev.* **9**, 32–45.

MAYNÉ, R. & GHESQUIÈRE, J. (1934). Hémiptères nuisibles aux végétaux du Congo Belge. *Ann. Gembloux*, **40**, no. 1. Brussels.

MIMEUR, J. M. (1946). Aleurodidae du Maroc (1re note). *Bull. Soc. Sci. nat. Maroc*, **24** (1944), 87.

MISRA, C. S. & LAMBA, K. S. (1929). The cotton white-fly (*Bemisia gossypiperda* n.sp.). *Bull. Agric. Res. Inst. Pusa*, no. 196.

MOSSOP, M. C. (1932). Cultural methods and tobacco whitefly in Southern Rhodesia. *Rhod. agric. J.* **29**, 869.

OTANES, F. Q. & BUTAC, F. L. (1939). Cotton pests in the Philippines. *Philipp. J. Agric.* **10**, 341.

PAOLI, G. (1931). Sull' arricciamento del cotone. *Atti primo Cong. Studi colon., Firenze*, April 1931.

PEARSON, E. O. (1948). Quelques notes sur la culture du cotonnier en A.E.F. *Cot. Fib. trop.* **3**, 61.

PRUTHI, H. S. (1939). Report of the Imperial Entomologist. *Sci. Rep. Agric. Res. Inst. New Delhi*, 1937–8, p. 113.

RUSSO, G. (1942). *Ann. Fac. agrar. Pisa* (N.S.), **5**, 436.

SOYER, D. (1947). La Psyllose provoquée par *Paurocephala gossypii* Russell. *Publications de l'Institut National pour L'Etude Agronomique du Congo Belge (INEAC). Série Scientifique*, no. 33.

TAKAHASHI, R. (1931). Some white-flies of Formosa. *Trans. nat. Hist. Soc. Formosa*, **21**, 203.

TAKAHASHI, R. (1936). Some Aleyrodidae from Micronesia. *Tenthredo*, **1**, 109.

TAKAHASHI, R. (1940). Some Aleyrodidae from Mauritius. *Insecta matsum.* **14**, 1.

TARR, S. A. J. (1949). The leaf curl disease of cotton (in the Press).

VAN DER LAAN, P. A. (1940). Motschildluis en *Eupatorium* als oorzaken van pseudo-mozaiek. *Vlugschr. Deli Proefst. Medan*, no. 67.

WOUTERS, W. (1948). Contribution à l'Etude Taxonomique et Caryologique du genre *Gossypium*. Ministère des Colonies de Belgique.