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Flax Rust and its Control

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UNIVERSITY FARM, ST. PAUL

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FLAX RUST AND ITS CONTROL[1]

By A. W. HENRY

INTRODUCTION

The rust of cultivated flax, *Linum usitatissimum* L., is virtually coextensive with the flax crop. It occurs in the seed-flax regions of Argentina, North America, India, and Russia; and the fiber-flax centers, most of which are in the eastern hemisphere. The disease is perhaps most commonly known simply as flax rust, but in Argentina it is called "polvillo" (dust) (15). In Ireland the term "rust" is applied to the uredinial stage while the telial stage is called "firing" (23), and in Friesland "zwartstip" (30).

In North America, rust has been reported on cultivated flax from nine states of the United States and from five provinces of Canada (33, 34, 35). Most of the North American crop is seed flax, grown chiefly for linseed oil, altho a small part of the straw is utilized for insulating, upholstering materials, and the like. A relatively small acreage of fiber flax is grown in eastern Canada and in two centers in the United States, one in eastern Michigan, and the other in the Willamette Valley of Oregon (21). Fish nets, twine, thread, mats, toweling, insulating and upholstering tow are the chief products. The seed is saved from much of the crop, and profits from its sale form an important part of the returns (9, 20, 21). Altho flax rust has recently been found in both of the fiber-flax districts of the United States, destructive epidemics apparently have not occurred. Every effort should be made to prevent the disease from spreading and becoming destructive.

DAMAGE FROM FLAX RUST

The chief injury to seed flax due to rust is a reduction in the yield of seed. This results from defoliation and from the fact that the fungus on the stem and other parts uses food materials which otherwise would go to form seeds. Flax plants usually are not killed by rust under field conditions, altho late-maturing plants of very susceptible varieties may be killed. In the greenhouse, seedling plants are frequently killed when artificially inoculated (Plate I, E and F). In

[1] Co-operative investigations between the University of Minnesota Agricultural Experiment Station and the Offices of Cereal Investigations and Fiber Plant Investigations of the United States Department of Agriculture.

the field, flax is usually beyond this stage before rust becomes sufficiently abundant to be destructive. The disease is apparently rather destructive in India; in fact, almost as important as black stem rust of wheat, reductions in yield of flax seed of 28 per cent of the crop having been reported there (8).

The average annual loss of seed flax from rust in North Dakota in 1923 was approximately 1 per cent (34). In 1924 rust was more abundant and the losses were heavier in both North Dakota and Minnesota than in 1923 (36). Estimated losses were reported in some fields as high as 10 per cent of the crop. Flax rust again did considerable damage in certain fields in 1925.

Rust may lower the yield of seed of fiber flax also, but the chief injury results from the direct effect of the fungus on the stems. It is naturally most destructive to flax grown for linen and other products requiring high quality fiber. Pethybridge and Lafferty (23) state that "'firing' not only spoils the appearance of the flax straw but renders it liable to break at the attacked spots, and affects the fibers in some cases. Moreover the black fungus tissue does not disappear during retting, and some of it at least remains adhering to the fibers even after scutching and hackling have been carried out." And Tobler (29), summarizing the effect of the disease on fiber flax, says: "from an industrial point of view flax rust does not only damage the fibers in the stems infected but it may even dissolve them. Moreover it prevents the decaying, thus causing 'measly' fibers. Stems of flax severely infected with rust fungi are useless and should be removed."

THE PATHOGENE

The flax rust fungus was first described in 1801 by Persoon (28), who called it *Uredo miniata* var. *Lini* Pers. It was transferred by Léveillé (19), in 1847, to the genus *Melampsora* and is now perhaps most commonly known as *Melampsora lini* (Pers.) Lév., altho, according to Arthur's classification (4), it is called *Uredo lini* Schum. Körnicke (31), in 1865, proposed a new variety, *M. lini* var. *liniperda,* for the rust on *L. usitatissimum*, since his observations indicated that this rust was distinct physiologically from that on *Linum catharticum.* Fuckel (13), in 1869, distinguished the rust on *L. usitatissimum* from that on *L. catharticum* on the basis of spore size, and called the former *M. lini* var. *major* and the latter *M. lini* var. *minor.* Palm (22), in 1910, made repeated unsuccessful attempts to infect *L. usitatissimum* with urediniospores from *L. catharticum* and also noted that the teliospores of the rust on cultivated flax were larger than those on *L. catharticum.* He therefore considered that the rust on *L. usitatissimum* was an independent species and called it *M. liniperda* (Körnicke) Palm. According to present ideas on the classification of the fungi (32), it is probable that the rust of cultivated flax would be regarded as a variety of *M. lini* rather than a new species, and on this basis Körnicke's name might well be retained.

Altho numerous wild species of *Linum* (4, 14, 28) are attacked by rust, it has been shown that there are sharp differences in the infection capabilities of several of these rusts (7, 22, 28). Some of them are apparently incapable of attacking cultivated flax. In the United States, rust has been reported on several wild species. Anderson (2), in 1889, reported that rust "was ruinous to *L. rigidum* in some seasons in Montana and sharply attacked *L. lewisii*." Galloway (14) in the same year pointed out that it had also been found on *L. virginicum* (in Iowa), *L. perenne* (in Montana, Arizona, and Nevada), and on *L. sulcatum* (in Iowa). Both refer to the possibility of the pathogene spreading to cultivated flax, but Galloway states that it had not been found on cultivated flax in the United States to his knowledge up to that time. Arthur (4) lists three additional species —*L. breweri* A. Gray, *L. congestum* A. Gray, and *L. drymarioides* Curran—as hosts of *M. lini* in California.

While it is known that the rust of cultivated flax can perpetuate itself readily in the absence of any wild species of *Linum,* it is possible that some of them may serve to increase the inoculum. Altho no reports of successful infection of cultivated flax with rusts from wild species have come to the writer's attention, it is quite possible that some of them can infect cultivated flax. A few cases of successful infection of wild species with rust from cultivated flax have been reported. Arthur (3) obtained successful infection of *L. lewisii* with telial material from cultivated flax; Pethybridge *et al.* (25) obtained slight infection of *L. angustifolium,* altho it evidently was not a congenial host; and Miss Hart (16) obtained successful infection of *L. rigidum* but not of *L. lewisii* with rust from cultivated flax. The writer, also, obtained negative results in attempts to infect *L. lewisii.* Arthur apparently must have had a different form of rust. Attempts to infect *L. perenne* and *L. grandiflorum* were also unsuccessful.

In 1906 Arthur (3) demonstrated that *M. lini* was eu-autoecious. He inoculated *L. lewisii* and *L. usitatissimum* with overwintered teliospores from cultivated flax and obtaind pycnia and aecia on both hosts. Arthur pointed out the obvious significance of his discovery on the control of the disease. Since then pycnia and aecia have frequently been found in the field. The uredinial and telial stages, however, are most familiar and most destructive. The former occurs as orange-yellow pustules on all green parts of the plant, especially on the leaves.

The telia are most conspicuous on the main stem and branches, where they form black, usually swollen, incrustations, altho they also occur on leaves, sepals, and bolls.

EPIDEMIOLOGY OF FLAX RUST

The aecial stage usually appears during the latter part of June in Minnesota and adjacent states, June 20 being the earliest date on which the writer has found rust in the field in Minnesota. The initial infections are few and inconspicuous. The uredinial or repeating stage usually does not appear until early July. Then several "generations" of spores must be produced before rust becomes abundant and generally distributed. Since each "generation" requires approximately ten days to develop, the disease usually does not reach its maximum severity until late July or early August. As the flax matures, the telial stage of the rust gradually replaces the uredinial stage. The uredinial stage, however, may persist on volunteer flax plants until killing frosts occur. Viable urediniospores were collected on volunteer flax in Minnesota in 1924 as late as November 11, after several severe frosts had occurred. There is no indication that the urediniospores overwinter and infect flax the following spring. Teliospores, however, readily overwinter and produce the inoculum (basidiospores) for initial infections in the spring.

An experiment was made to determine if differences in soil water level on peat would have any effect on rust development. The same variety of flax was sown on plots having different soil water levels varying approximately from one to five feet from the surface. The flax plants were shortest and least thrifty on the five-foot water level, most vigorous on the intermediate water levels, and matured first and were moderately vigorous on the one-foot water level. As shown in Table I, rust infection was considerably lighter on the flax on the two extreme water level plots than on that on the intermediate water levels. In general, where the plants were most vigorous, rust was the heaviest. Regulation of the soil water level could hardly be recommended, therefore, as a control measure for rust. Considering both the growth of the plants and the severity of the rust, maintenance of the soil water level relatively near the surface seems to be preferable to the other extreme.

TABLE I

EFFECT OF DIFFERENT SOIL WATER LEVELS ON THE DEVELOPMENT OF FLAX RUST*

Water level	Per cent rust			
	Saginaw flax 1923	Saginaw flax 1924	Winona flax 1925	3-year Av.
1-foot..........	23	10	35	22.7
2-foot..........	50	13	75	46.0
3-foot..........	70	18	70	52.7
4-foot..........	55	15	70	46.7
5-foot..........	27	13	30	23.3

* Water level controls were installed and maintained by members of the Division of Agricultural Engineering, University of Minnesota, to whom grateful acknowledgment is made for their kind co-operation. Actual levels at which water was held in 1925 were 1.1, 2.1, 3.1, 3.9, and 4.5 feet, respectively.

VARIETAL RESISTANCE

Differences in resistance of varieties of *L. usitatissimum* to *M. lini* have been noted by several workers. Bolley (6), as early as 1903, noticed that different strains of flax reacted differently to rust. Sydow *et al.* (27) reported that European varieties remained free from rust in India while indigenous varieties were severely attacked. Eriksson (12) noted that different sorts showed varying susceptibility. Butler (8) mentioned a variety at Pusa, India, which had never been attacked. Westerdijk (30) stated that rust was known in Holland only on the white-blossomed flax. Girola (15) pointed out that "Lino mal Abrigo" (a group of Argentine varieties having medium-sized seed) was noted for its resistance to "polvillo." Howard (18) reported that of three classes of flax varieties (large-seeded, medium-seeded, and small-seeded) grown at Pusa, India, varieties of the last class did not suffer from rust and other diseases. Dorst (11) recently isolated rust-resistant strains of fiber flax in Holland, and Dillman (10) reported that certain Argentine flaxes were nearly immune from rust in the United States.

In these investigations, varietal tests have been made for several years, and distinct differences in varietal resistance have been found. The principal rust nursery has been on peat soil near St. Paul, since rust usually develops abundantly each year on flax grown on the low-lying peat bogs, whereas it often is much less prevalent on flax on higher land. Previous to 1924, this nursery was at Clearspring, Minn., while in 1924 and 1925 it was at Coon Creek, Minn. Infected straw from the previous year's crop was spread over the plots to increase the inoculum, and in 1924 and 1925 the plants were dusted or sprayed with fresh urediniospores from the greenhouse. In 1924 several varieties were tested also at Mandan, N. D., and at East Lansing, Mich., but no artificial inoculum was applied to these plots. Rust, however, did not develop at East Lansing, so no data were obtained there.[2] The varieties were also artificially inoculated in the greenhouse as a check on the field results.

The most important result of these tests was the finding of varieties and strains of flax entirely immune from rust (17) (Plate I). In tests made in 1921 and 1922, Barker[3] noted that Chippewa, Minn. 182 (5) showed some resistance, and that a lot of commercial large-seeded Argentine flax obtained from the linseed mill of the Pittsburg Plate Glass Company, at Red Wing, Minn., was immune. The writer has subsequently isolated numerous immune pure lines from this and other samples of Argentine flax obtained from the Red Wing linseed mill and from the American Linseed Company, of New York. Most of these have large dark blue flowers and large brown seeds, but several other distinct types are represented. In addition to the blue-flowered sorts, immunity has also been found in white-blossomed yellow-seeded varieties. For instance, Ottawa 770B, a Canadian variety obtained in 1923, has been consistently immune in all tests. This variety has small white flowers with crinkled petals, yellow seed, and moderately long stems. Immune strains have also been found in Williston Golden, a short-stemmed variety having rather large white flowers and yellow seed. Several other varieties or strains, mostly of the large brown-seeded Argentine type, obtained from A. C. Dillman, Agronomist in charge of Seed Flax Investigations, United States Department of Agriculture; and several varieties obtained from India by A. C. Arny, of the Division of Agronomy, University of Minnesota, have proved immune or highly resistant in tests made in Minnesota.

Practically all varieties of seed flax commonly grown in the United States, including such wilt-resistant varieties as North Dakota No. 114 and Winona (Minn. No. 182), are susceptible to rust. All strictly fiber varieties so far tested, such as Saginaw, also are susceptible. However, there is considerable variation in the degree of infection on varieties classed as susceptible in the field. Such differences are often much less pronounced when seedlings are inoculated in the greenhouse.

Of the varieties found immune, Ottawa 770B most nearly approaches the fiber type. The stems of this variety, however, are too short and coarse for a good fiber variety. It was thought that the rust-resistant fiber strains which Dorst (11) isolated in Holland might

[2] Grateful acknowledgement is made for providing land and facilities for these tests to the Division of Agricultural Engineering, University of Minnesota, for the tests at Clearspring, Minn.; the Division of Soils, University of Minnesota, for those at Coon Creek, Minn.; A. C. Dillman and J. C. Brinsmade for those at Mandan, N. D.; and Dr. A. D. Suttle for those at East Lansing, Mich.

[3] Dr. H. D. Barker, formerly of the Division of Plant Pathology, was in charge of the early work on the flax rust project, under Dr. E. C. Stakman.

be valuable in the United States. Dorst kindly sent five of his selections to the writer. One of these had never shown rust, one was very resistant, two were fairly resistant, and one was susceptible in Holland. They were tested in the greenhouse at St. Paul and in two places in the field in Minnesota, but in each test all five strains proved susceptible. Evidently, therefore, they could not be recommended as rust resistant in the United States. The results can readily be explained if it is assumed that the rust on cultivated flax consists of several different physiologic forms and that forms capable of attacking these strains occur in Minnesota but not in Holland, where they were originally tested. In fact, similar distribution of forms has actually been demonstrated for *Puccinia graminis avenae* Erikss. and Henn., the cause of stem rust of oats, by Stakman, Levine, and Bailey (26). The variety White Tartar is resistant to forms of this rust occurring in the United States, but is entirely susceptible to two forms occurring in Sweden.

Table II gives the percentage of rust and relative wilt resistance in the field, in 1924, of five varieties which have been used in breeding investigations for the development of improved immune varieties.

TABLE II

RELATIVE RUST RESISTANCE OF FIVE VARIETIES OF FLAX GROWN IN 1924 AT THREE DIFFERENT PLACES AND RELATIVE WILT RESISTANCE AT ST. PAUL

Variety	Percentage of rust*			Relative wilt resistance
	Clearspring, Minn.	Coon Creek, Minn.	Mandan, N. D.	Univ. Farm, St. Paul
Saginaw	15.0	30.0	27.5	MR†
Winona	20.0	41.6	27.5	R
Chippewa	25.0	30.0	25.0	R
Argentine selection	0.0	0.0	0.0	R
Ottawa 770B	0.0	0.0	0.0	MR

* Artificial epidemic created at Coon Creek, natural epidemic at Clearspring and Mandan.
† MR, moderately resistant; R, resistant.

SELECTION

The simplest and most rapid method of producing rust-resistant varieties of flax, provided resistance could be found in plants of the desired type, is simply to select resistant plants and multiply them. Unfortunately, it is often impossible to find resistant plants which are otherwise desirable.

As rust is very destructive to fiber flax, numerous selections have been made from fiber varieties. The better fiber-flax varieties, such as Saginaw, were heavily inoculated both in the field and in the greenhouse. Plants which showed only traces of infection, and a few which remained entirely free from infection, were selected. The progenies from these selections were later inoculated with rust and in most cases proved susceptible, indicating that the plants originally selected had merely escaped infection and were not truly resistant. None of the selections from the strictly fiber varieties proved immune. Some appear to be more resistant than the varieties from which they were selected, but it would seem much better to obtain through hybridization a selection entirely immune from rust.

Rust-immune varieties of seed flax already exist, as has been previously pointed out. Some of these doubtless can be improved by selection, and individual plant selections have been made from them with this end in view, as well as from numerous samples of commercial flax. Further improvement no doubt can be made by crossing the immune varieties with susceptible varieties in order to combine rust immunity with higher yielding ability, resistance to other diseases, and other desired characters.

HYBRIDIZATION STUDIES

As no rust-immune strains of fiber flax have yet been found in our studies, the most hopeful method of producing them is by crossing the susceptible fiber varieties with immune seed varieties and then selecting the segregates possessing the desired fiber characters and immunity from rust. It may also be possible to isolate, from the progenies of such crosses, immune fiber strains having the capacity for greater seed production than varieties of fiber flax now in use. These would be valuable for districts where both seed and fiber are saved. By selecting suitable parents, it should also be possible to combine wilt resistance and immunity from rust in desirable varieties of both fiber and seed flax.

Crosses have been made with these ends in view. The reaction to rust and wilt shown by the principal varieties used as parents in these crosses is given in Table II. It will be noted that the two immune parents, Argentine selection and Ottawa 770B, were immune from rust at three different places where they were tested. They have also been inoculated in the greenhouse with several other North American collections, including one from the fiber-flax section of Michigan and one from western Canada. They have been immune from all collections tested and are therefore valuable parents for crosses. The Argentine selection is also decidedly wilt resistant (Plate II, C.). Saginaw, the principal fiber parent used, is an exceptionally tall variety but is not a high seed producer. It is moderately resistant to wilt but quite susceptible to rust. Winona and Chippewa were used in crosses with the rust-immune varieties in order to combine their resistance to wilt with immunity from rust.

F_1 plants in all crosses made have been immune, indicating the dominance of immunity over susceptibility. Segregation for these characters occurred in the F_2, the type of segregation differing in different crosses. Numerous promising plants have been selected from this generation, and F_3 families of some of the Argentine crosses have been grown. Many of the selected plants were immune from rust and possessed other desired characters, indicating that immunity from rust can be obtained in different morphological types. There is every reason to believe that immune strains of both fiber and seed flax can be developed from these crosses. When the selections become homozygous or nearly so for rust immunity and other characters, they will be grown on wilt-infested soil and only the most wilt-resistant ones will be saved.

RELATION BETWEEN RUST RESISTANCE AND WILT RESISTANCE

Flax wilt caused by *Fusarium lini* Bolley is recognized as the most destructive disease of flax in the United States. As the pathogene is transmitted by the seed and can live saprophytically in the soil for many years, it is likely to follow the crop wherever it is grown. Fortunately, wilt can be controlled by the use of resistant varieties. Bolley (6), of the North Dakota Agricultural Experiment Station, was the first to recognize the importance of this in the United States, and several resistant varieties have subsequently been distributed by the experiment stations of North Dakota, Minnesota, and other states.

In developing rust-immune varieties of flax it obviously would be very desirable to have them resistant to wilt also. With this end in view, varieties under investigation for rust resistance have also been grown on soil infested with the wilt organism. The results of the combined studies indicate that there is no correlation between rust resistance and wilt resistance. Apparently resistance to the two diseases is not due to the same causes. Winona flax is resistant to wilt (Plate II, B and D) but is particularly susceptible to rust, whereas Saginaw is moderately resistant to wilt but susceptible to rust. On the other hand, certain strains of Williston Golden are immune from rust but are very susceptible to wilt (Plate II, A), while Ottawa 770B is immune from rust but moderately resistant to wilt. However, the fact that both wilt resistance and immunity from rust are found in strains of Argenine flax (Plate II, C) indicates that the two are not incompatible. It seems possible, therefore, to combine wilt resistance and immunity from rust in other varieties of seed flax as well as in fiber flax.

One of the major problems at present in connection with wilt-resistant varieties which have been distributed, is the matter of keeping them pure. Winona, for instance, differs from most of the seed flax grown in the Northwest only in the ability to resist wilt. Neither the seeds nor the plants can be distinguished in general appearance from many unselected lots of commercial flax which are susceptible to wilt. Mixtures or natural crosses might occur and not be detected until susceptible lines thus introduced had increased to such an extent as to result in serious losses from wilt. Careful certification, coupled with the education of the grower to the importance of growing his own seed, will largely avoid this danger. In addition, however, it would obviously be very desirable if some reliable test of the purity of wilt-resistant varieties could be made. Since wilt resistance is only relative, and varies with temperature and other environmental factors, a greenhouse test on disease-infested soil is not satisfactory for determining the purity of wilt-resistant flax. By combining in one variety both wilt resistance and immunity from rust, however, a very good check could be made of its purity by simply inoculating it with rust in the greenhouse. Large numbers of such tests could be carried out rapidly and with comparatively little labor. All plants susceptible to rust would constitute impurities. The present likelihood of mixture with other immune flax is not great. Immunity from rust would at least constitute an important distinguishing characteristic. Similar methods of detecting impurities have been used in other crop plants. The literature on the subject is summarized by Aamodt and Levine (1).

DISSEMINATION OF FLAX RUST WITH THE SEED

The attention of the writer was first attracted to this problem in 1922 by the experience of R. L. Davis, then in charge of fiber flax breeding investigations at East Lansing, Mich., for the office of Fiber Plant Investigations, United States Department of Agriculture. Mr. Davis stated that flax rust had occurred in his plots but once and then only on a few rows of a single (Japanese) variety. He immediately destroyed all the plants of the rusted variety and did not observe rust in his plots subsequently. The question naturally arose as to why there was rust on only one variety. The natural supposition was that it might have come from the seed. On looking over the literature on flax rust it was found that Pethybridge *et al.* (25), in Ireland, reported that flax rust could be transmitted to the following crop if fragments of the black or telial stage were sown with the seed.

The following experiment was made in 1924 to ascertain whether there was danger of transmitting flax rust with the seed in the United States. Winona flax was sown in three plots in an isolated corner of a sunflower field. Plot E was sown with seed which had been thoroly dusted with viable urediniospores. Clean seed was sown in Plot F, while the seed for Plot G was mixed with telial fragments approximately ⅛ inch in length. Each plot consisted of six rows, the three plots being separated only by two-foot alleys. They were sown at the same time, during the last week of May.

The earliest appearance of rust in these plots was noted on July 15 in Plot G. On July 1 careful counts were made of the percentage of rusted plants in the different plots. Six hundred plants, one hundred in each row, were counted in each plot. In spite of this careful survey, not a single rusted plant was found in any row of either Plot E or Plot F, that is, those sown with seed dusted with urediniospores and with clean seed, respectively. On the other hand, pycnia and aecia were found on plants in every row of Plot G, where telia were mixed with the seed, the percentage of infected plants in the different rows ranging from 1 to 10 per cent. Naturally, after these initial infections occurred, the rust tended to spread to the other two plots. After ten days a trace of uredinia was found in each of the other two plots. By September 20, rust was general on all three plots, as shown in Table III.

TABLE III

DATA ON TRANSMISSION OF FLAX RUST WITH SEED

Plot No.	Seed treatment	Date examined	Percentage of plants infected					
			Row numbers					
			1	2	3	4	5	6
E	Seed dusted with urediniospores	July 16	0	0	0	0	0	0
F	Clean seed	July 16	0	0	0	0	0	0
G	Telia mixed with the seed....	July 16	2	4	1	10	4	2
E	Seed dusted with urediniospores	Sept. 20	30	46	58	56	40	36
F	Clean seed	Sept. 20	60	66	60	58	46	44
G	Telia mixed with the seed....	Sept. 20	36	40	36	32	38	52

These results indicate that even tho the seed should become dusted with viable urediniospores and the flax sown immediately, there would be little danger of the seedlings becoming infected. Moreover, in the principal flax-growing areas of the United States the seed is always sown in the spring, so that urediniospores, which are relatively short-lived, would not survive the winter anyway. There seems little danger, therefore, of initial infections arising from this source, at least in the Upper Mississippi Valley. The results do indicate that flax rust can readly be carried from one crop to the next, not by the seed itself but with it in the form of bits of telia-laden straw. Even tho the seed be planted in soil that has never before borne a crop of flax, the infection may be introduced with the seed in this way. A few initial infections could supply inoculum for a heavy infection of the whole field if conditions favorable to the pathogene should occur.

Another important matter arising out of the transmission of flax rust with the seed is the danger of introducing rust from other countries. With most rusts there is little danger of dissemination by the seed, but with flax rust there is a probability that it might be introduced in this way. Moreover, it is quite possible that a form of flax rust virulent on our resistant varieties, may occur in some other country and might be introduced with the seed. The fact already mentioned, that a selection of fiber flax introduced from Holland was susceptible to rust in this country while it never became rusted in Holland, indicates that flax rust in that country may be different from ours. Since Argentine selection and Ottawa 770B, which have been used largely as rust-immune parents in our breeding work, have proved immune to collections of rust made in Michigan, Minnesota, North Dakota, and western Canada, it is hoped that they will prove generally immune to flax rust occurring in this country and that no rust forms will be introduced from other countries which can attack these varieties.

CONTROL MEASURES

USE OF IMMUNE VARIETIES

The use of immune varieties offers the best means of controlling flax rust. As has been pointed out, immunity has been found in several types of seed flax and results indicate that it can be transferred to fiber varieties and more desirable seed varieties by crossing. Moreover, strains of seed flax have been found which are both resistant to wilt and immune from rust, so it seems possible to combine these qualities in strains of fiber flax and possibly in better strains of seed flax. The varieties in use at the present time, however, are nearly all susceptible to rust, so it will take several years to replace them even after immune varieties are introduced. While susceptible varieties are still grown, therefore, other measures should be taken to avoid damage from flax rust.

CARE OF THE SEED

Thoro cleaning of the seed is advisable, not only to remove foreign seeds but also as a preventive measure against rust and other diseases. Small bits of straw and chaff are almost invariably present in samples of uncleaned seed and these may carry inoculum to the following crop, especially if the previous crop was diseased. Diseases like wilt, pasmo, and browning may be transmitted on or in the seed itself, so that cleaning can not entirely remove inoculum from the seed. But with rust, fragments of straw or chaff bearing telia are apparently the only carriers of inoculum which may be transmitted with the seed, and these can readily be removed by the fanning mill.

Many growers follow the practice of changing their seed every year or two. Not infrequently seed is obtained from distant sources and even from other countries. This is unwise, because rust may thereby be introduced into a district previously free from it. The same is true for several other destructive diseases of flax. In fact, if the seed is frequently changed, it is almost impossible to avoid the introduction of disease with it. The safest practice is for the grower to obtain seed of a recommended variety from his nearest experiment station and then to save his own seed for the following year, rather than purchase it each year from an outside source.

TIME OF SEEDING

Tobler (29) noted that under European conditions flax rust was more abundant late in the season and injured the stems of late-sown flax to a greater extent than those of early-sown flax. The same holds true in the flax centers of North America—rust is likely to be most destructive on late sowings. Early sowing is also a good preventive measure for wilt (5). In the north central part of the United States, flax can in most seasons be sown during the latter part of April without danger of serious injury from frost.

Table IV shows the relative severity of rust on flax sown at different dates at University Farm in 1923 and 1924. In 1923 rust was abundant in these plots, while in 1924 it was very light, infections occurring only on the plants in the seedings of the last two dates.

TABLE IV

EFFECT OF TIME OF SEEDING ON DEVELOPMENT OF FLAX RUST*

Time of seeding	Severity of rust 1923	Severity of rust 1924
Usual time	T†	o†
10 days later	T	o
20 days later	L	o
30 days later	MH	o
40 days later	M	T
50 days later	H	T

* Data obtained from plots of the Division of Agronomy and Farm Management, University of Minnesota, through the courtesy of A. C. Arny.

† o, none; T, trace; L, light; M, medium; H, heavy.

Since flax rust does not become abundant under field conditions until midsummer, it is evident that early-sown flax will be exposed to infection for a much shorter period of its growth than late-sown flax.

If seedling flax plants are severely attacked by rust, they may be badly stunted and many of them may be killed. In Plate I, E and F, the effect of inoculating young seedlings of Winona and Saginaw flax in the greenhouse is shown in comparison with the immune Argentine selection, subjected to exactly the same conditions. Such severe injury would rarely occur in the field. However, when susceptible varieties are sown very late they may be so severely attacked that the plants may be killed or prevented from forming seeds. When immune varieties come into use, time of seeding will have no importance in this respect, as such plants are immune at all stages.

CROP ROTATION

With wilt-resistant varieties coming into more general use, some growers feel that they are safe in growing flax several years in succession on the same land. This practice, however, is conducive to the accumulation of rust and other diseases to which the wilt-resistant flax may be susceptible. As long as rust-susceptible varieties are grown, flax should not be sown on land devoted to flax the previous year. Corn or one of the legumes has been shown to be among the best crops to precede flax (10). As was first demonstrated by Arthur (3), the rust may overwinter in the telial stage on infected stubble and old straw left on the field, and is almost sure to infect susceptible varieties sown there the following year. If conditions become favorable for the pathogene, a serious epidemic may occur. Flax invariably should be grown in a rotation with other crops if at all possible.

CHOICE OF LAND

In addition to avoiding land that produced flax the previous year, it is well, from the standpoint of rust, to sow flax on relatively high land. On low-lying soils maturity is usually delayed and moisture conditions are more often favorable for rust infection than on higher land. For instance, in years when flax rust is relatively scarce on ordinary soils in the vicinity of St. Paul, it often is abundant on low-lying peat bogs; and infections, in general, are usually heavier every year on such land.

SANITATION

As long as susceptible varieties are grown, sanitary measures, consisting of the destruction or removal of infected straw after a diseased crop, will aid in the control of flax rust. This can be accomplished best by burning before the new crop emerges. If this is not done, the infected straw should at least be removed from the vicinity of fields intended for flax.

SUMMARY

1. Flax rust is an important disease of both seed and fiber varieties of *Linum usitatissimum,* but is especially important on the latter. It occurs in all the major flax-growing regions of the world.

2. The disease may reduce the yield of seed flax and may ruin the stems of fiber flax for fiber purposes and prevent proper retting.

3. *Melampsora lini* (Pers.) Lév. is the name commonly applied to the rust of *Linum spp.* However, distinct forms occur on different species of *Linum,* as noted by several workers. The rust of cultivated flax was described as a new variety, *M. lini* (Pers.) Lév. var. *liniperda* Körnicke, in 1865; and as a new species, *Melampsora liniperda* (Körnicke) Palm, in 1910. It apparently is deserving of at least the former rank. The rust is eu-autoecious, as was demonstrated by Arthur in 1906. All spore forms occur in the field, the uredinial and telial stages being most prominent and most destructive.

4. In Minnesota and neighboring states, the disease appears first during the latter part of June but does not assume epidemic form until late July or early August. The uredinial stage may persist until killing frosts occur, but apparently does not overwinter. The telial stage readily overwinters and starts the initial infections the following year.

5. In an experiment on a peat bog, flax was sown on five plots having water levels varying approximately from one to five feet from the surface. Heaviest infections of rust occurred on the intermediate water levels, where the flax was the most vigorous.

6. Altho all of the long-stemmed varieties of fiber flax thus far tested and most of the commonly grown varieties of seed flax are susceptible, sharp differences in varietal resistance occur. Immune varieties of both blue- and white-blossomed seed flax have been found. Thus numerous immune strains of large brown-seeded, blue-flowered, Argentine flax and immune strains of the yellow-seeded, white-blossomed Williston Golden flax have been isolated. Ottawa 770B, another white-blossomed, yellow-seeded variety having stems of intermediate length, also is immune.

7. Ottawa 770B and certain strains of Argentine flax were tested with rust from Canada and from several states of the United States and proved immune to all collections. They were used as parents in crosses with susceptible varieties of fiber flax, as selection alone of fiber varieties did not yield immune strains. Crosses were also made with wilt-resistant varieties of seed flax.

8. The F_1 plants of all crosses were immune, indicating that immunity is dominant in these crosses.

9. Segregation occurred in the F_2 and the behavior of the segregates indicates that it will be possible to combine immunity from rust with fiber characteristics or with other desired characters.

10. Certain strains of Argentine flax, in addition to being immune from rust, are highly resistant to wilt, so it should be possible to obtain wilt-resistance and immunity from rust in a fiber variety as well as in seed varieties.

11. Wilt-resistance and immunity from rust are not necessarily correlated. They apparently are determined by different causes. Winona, for instance, is resistant to wilt but susceptible to rust and strains of Williston Golden are very susceptible to wilt but immune from rust.

12. When both wilt-resistant and rust-immune varieties are in use, the latter characteristic will be of real value in testing them for purity. Greenhouse tests for immunity from rust can readily be made, whereas greenhouse tests for wilt resistance are not satisfactory.

13. The fact that certain rust-resistant strains and one apparently immune strain of fiber flax from Holland were susceptible when tested in the United States indicates that the rust of cultivated flax may be specialized into physiologic forms.

14. When bits of straw bearing telia were sown with the seed of a susceptible variety, infection of the following crop resulted. This confirms similar investigations conducted in Ireland, and emphasizes the importance of thoroly cleaning the seed. It also indicates the danger of introducing seed from other countries, as virulent forms of rust might be introduced in this way.

15. The use of immune varieties is the most promising control measure. As soon as suitable immune varieties are developed and generally distributed, other control measures naturally will cease to be of value. Because of the destructiveness of flax wilt, the immune varieties used should also be resistant to wilt.

16. While susceptible varieties are still in use, preventive measures should be taken to avoid flax rust: home-grown seed should be used where possible, and it should be thoroly cleaned to remove bits of straw; seeding should be done early; low-lying soils should be avoided; and on fields intended for flax, infected straw should be burned or removed before the new crop emerges.

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EXPLANATION OF PLATES

PLATE I

Flax Varieties Susceptible to or Immune from Flax Rust

The leaves shown at A, B, C, and D were taken from plants of four different varieties of flax grown under the same conditions in the field and subjected to a heavy epidemic of rust. Leaves in A and C are from the susceptible varieties Winona and Saginaw, respectively, while those in B and D are from the immune variety Ottawa 770B and Argentine selection, respectively.

The effect of heavy inoculation of young seedlings in the greenhouse is shown in E and F. The tall plants on the left in both E and F are of the immune Argentine selection. The plants on the right in E are of Saginaw and on the right in F are of Winona. Saginaw is one of the best fiber-flax varieties and Winona one of the best wilt-resistant seed-flax varieties now in distribution in the United States. They are being bred with rust-immune varieties to combine this characteristic with their good qualities. The photograph was taken several weeks after inoculation.

PLATE II

A Portion of the Flax Wilt Nursery, University Farm, St. Paul, in 1924

Row C is Argentine selection, showing that it is highly wilt-resistant as well as being immune from rust. Rows B and D are checks of Winona, also highly wilt-resistant but susceptible to rust. Row A was sown with Williston Golden, a variety extremely susceptible to wilt but some strains of which are immune from rust. Varieties in the rows on either side of C show moderate susceptibility to wilt.

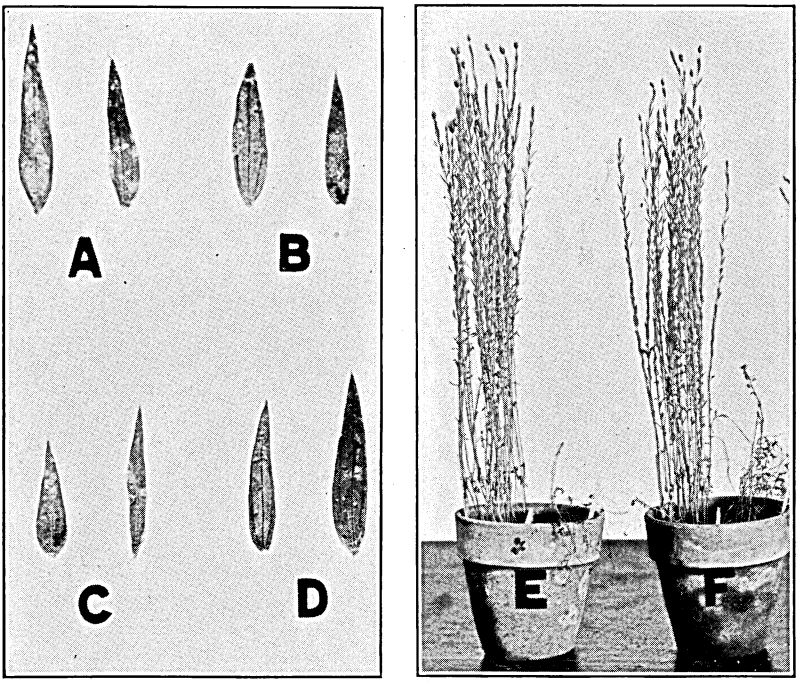

PLATE I

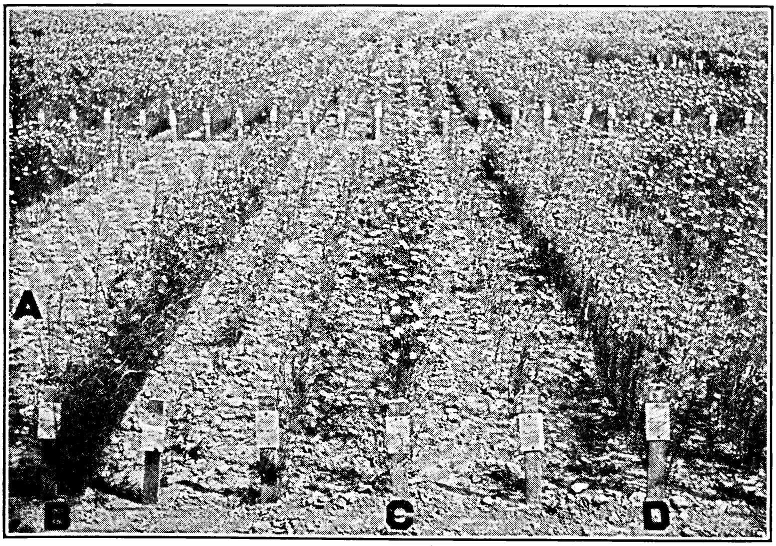

PLATE II

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