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STUDIES ON MINAMI VARIETY, A WILT RESISTANT FLAX

By

Muneo KIKUCHI

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I. Introduction

In the cultivation of flax in Japan three important diseases, wilt, anthracnose and rust have been found to be most serious menaces. Among these, the wilt caused by *Fusarium Lini* BOLLEY causes the greatest damage, for the fungus lives in the soil and,

causing so-called flax sick soil, attacks the crops year by year successively with increasing severity until their annihilation. The preventive method usually adopted is only the rotation of crops with six to seven or more years' interval. Such a rotation of crops with long years' interval decreases the efficiency of the agricultural production. In order to avoid this inconvenience the breeding of a wilt resistant flax variety should be one of the most important problems in flax cultivation.

In this connection many worthy efforts have been made previously by plant-pathologists and plant-breeders. We have a precious wilt-resistant variety of flax which was selected and bred by the late Emer. Prof. TAKAJIRO MINAMI at the Faculty of Agriculture of the Hokkaido Imperial University. Since 1932 the writer has studied the nature of the wilt resistance of this variety with regard to the influences of environmental conditions on some physiological characters, and on the inheritance of its wilt resistance, to find out some fundamental data helpful to the further progress of the breeding of wilt-resistant flax.

The writer has the great pleasure to express here his heartiest respect and thanks to the late Emer. Prof. T. MINAMI to whom he is indebted for the material. He wishes also to acknowledge deeply his sincere gratitude to Emer. Prof. MASAO AKEMINE, Prof. SEIYA ITO, and Prof. YOSHIHIKO TOCHINAI of the Hokkaido Imperial University for their valuable suggestions and kind advices throughout the course of this work and for their suggestive criticisms while this paper was in preparation. It is also his great pleasure to express appreciation for the kindness of Prof. YOSHICHIKA SHIMA in offering encouragement and useful advice during this work. Further the writer is indebted to Mr. KEIJIRO YOSHIDA for his great help in both field and laboratory work.

II. The historical review of the flax wilt disease and the wilt resistant varieties

The wilt disease of flax has been noticed as an important menace to flax cultivation from olden times, and in Europe the rotation of crops has been customarily adopted to prevent the damage. The real cause of the disease, however, long remained

unknown until it was first found in Japan in the last decade of the 19th century.

In 1890 Luggar studied the wilt disease of flax and threw light on the details of the disease, but he could not find the pathogene. In Japan, however, Prof. MIYABE (1892) first found that the wilt disease of flax is caused by an attack of a parasitic fungus, and he stated that it was a species of *Fusarium*. BROEKEMA (1893) also found that the "Vlasbrand" or the "Brand" of flax is caused by a parasitic fungus, and he pointed out some individual plants surviving in sound state owing to their strong resistance to the disease. He found further that this resistant character of the plants is hereditary and that the descendants of these resistant plants show the parental characteristics. He assumed that the seeds of the resistant plants had strong vitality and this is the very reason why they show the disease resistance. NAOHARU HIRATSUKA (1896) studied this disease under the direction of Prof. MIYABE and found that the causal fungus can live on organic matters in soil and attacks eventually the flax seedling growing on that soil; accordingly the rotation of crops with a long interval adopted in Europe for flax cultivation is an effective sanitary method for preventing the occurrence of the wilt disease.

In 1901 BOLLEY, a Professor in the North Dakota Agricultural College, pointed out the true nature of the disease and found the causal fungus of the flax wilt quite independently from the discovery of it made by Prof. MIYABE in Japan. He named the fungus *Fusarium Lini* n. sp.

After the confirmation of the causal fungus by BOLLEY, the physiology of the fungus and pathology of the disease have been studied by several investigators. BOLLEY (1901) assumed that the wilt symptom is derived from the disturbance of water-ascending due to the stoppage of vessels by development of mycelium. TISDALE, in 1916, reported on the temperature relation to the fungus that the minimum, optimum and maximum temperatures of the mycelial growth were 10°–11°C., 26°–28°C., and 35°C. respectively. In the next year, 1917, he further reported an extensive study of this disease. The fungus attacks flax seedlings growing on sick soil mostly on the root-hairs. As he did not find the stoppage of vessels by mycelium as described by BOLLEY, he offered new pathological explanations of the morbid changes of wilt disease that (1) shortage of the water- and nutrition-supply is due to the partial destruction

of the root-system by the fungus; (2) partial seizure of the water and nutrition supply of the host plant is made by the parasite; (3) increase of the fungus development and transpiration of the host plant is caused by a rise of air temperature; (4) poisoning of the protoplasm of the host plant by some toxic secretes of the parasite occurs.

In 1920, TOCHINAI published two papers on the flax wilt disease. In one of them he reported experimental results of seed-disinfection by formaline and the effects of soil heating upon the growth of flax seedlings with the purpose of preventing the wilt disease. In the other paper he dwelt upon the nutritive physiology of the causal fungus, *Fusarium Lini* BOLLEY, on several kinds of carbon and nitrogen sources. In the next year, 1921, the same author again published two papers in one of which he reported the fermentation of carbohydrates by *Fusarium Lini.* In the other paper, various physiological characters of the fungus were described and the minimum, optimum and maximum temperatures for the mycelial development of the fungus in thermostat were recorded as 10°–12°C., 30°C. and 36°–37°C. respectively.

In 1926 TOCHINAI published a thesis concerning extensive comparative studies of the wilt disease and anthracnoses of flax, and in this he dwelt upon the pathology of rapid wilting of flax seedlings on the basis of the results obtained in his physiological investigations of *Fusarium Lini.* He said that gas production caused by decomposition of carbohydrates and alkalinization of cell contents caused by metabolism of amino-acids by the fungus occurring mostly of the root system or basal part of the seedling would cause the death of cells there and accordingly cause the rapid wilting of the upper part without showing any peculiar necretic lesions.

Concerning the wilt-resistance of flax varieties, BROEKEMA (1893) first found some highly resistant individuals in flax fields where severe ravage by the wilt disease took place, and he succeeded in selecting some resistant flax strains from them. Later on, BOLLEY (1903, 1907), in the North Dakota Agricultural Experiment Station, selected some flax strains highly resistant to the wilt from seeds obtained in the market.

Concerning these wilt-resistant flax strains selected by BOLLEY, TISDALE (1917a) studied their anatomical characters and Stakman et al. (1919) carried out genetical studies.

BARKER (1923) experimented on the disease resistance of the flax strains selected in the Minnesota Agricultural Experiment Station and reported that the strain named Chippewa had high resistance to the wilt and rust. According to DILLMAN (1929), three varieties "Hinota" "Redwing" and "Winona" were proved to be resistant to wilt disease at the North Dakota Agricultural Experiment Station. BURNHAM (1932), carried out genetical studies of the wilt-resistance with a variety selected in North Dakota and also of its hybrids with other varieties on sicksoil first inoculated artificially with *Fusarium Lini* and followed by continuous flax cropping for several years.

At the Faculty of Agriculture of the Hokkaido Imperial University the late Emer. Prof. T. MINAMI selected several strains resistant to the wilt disease from Riga variety, during his long experiments on the succession cropping of flax. On one of these strains of Dr. MINAMI, TOCHINAI (1920a) has already proved their high resistance to the wilt disease in local field conditions in Sapporo. MINAMI (1929) himself reported the comparatively vigorous growth and plenteous yield of this strain on the sick soil and in his last joint paper with the writer (1934) reported on some characteristris of the same strain. Recently the present writer (1934, '35, '36, '37,) reported his studies on the morphological, physiological and genetical aspects of the same material.

III. Materials

Material used in the present experiment were fifteen varieties of flax obtained from the experimental farm of the Faculty of Agriculture of the Hokkaido Imperial University. Most experiments were carried out principally with a resistant strain bred up from Riga by the late Prof. Emer. T. MINAMI and its original variety.

A series of experiments on the successive cropping of the principal crops in Hokkaido was started in 1892 by Prof. MINAMI in the experimental farm of the Faculty of Agriculture of the Hokkaido Imperial University, and it is continuously kept up to the present time. Flax is used as an important crop in this experiment. In the first ten years of the experiment, Rusian and Belgian varieties of flax were planted. The experimental plot became "sick soil" certainly due to the successive cropping of flax, and the wilt-disease

occurred so severely as almost to annihilate the entire crop. In 1902 Riga variety was grown in the same plot and a few individuals survived on the sick soil being highly resistant to the wilt disease. From these surviving individuals several resistant strains were secured by selection. The resistant flax strain used in the present studies belongs to the strain numbered M 63–24–4–4–4, and it has shown the highest resistance to the wilt disease.

The writer wishes to name this wilt resistant flax strain "Minami Variety" in honour of its breeder, the late Prof. Emer. TAKAJIRO MINAMI, considering its peculiarities in the morphological characters and high resistance to the wilt disease. The other varieties used for comparison are all susceptible to the wilt disease, and they are pure lines cultivated in the same experimental farm by means of rotation cropping of seven or more years. Detailed data on the flax varieties used in the present experiments are given in the following table.

TABLE 1. Names and origins of the flax varieties used in the experiments.

Variety name	Origin	Start of cultivation in the exp. farm of the H. I. U.
Chokeishu	Hokkaido Agr. Exp. Stat.	1907
Shinkokuama	do.	1922
Hokkaido zairaishu	do.	do.
Ichigoshu	do.	1896
Indoshu	do.	9 22
London	do.	do.
France	Teikoku Seima Co.	1897
Holland	do.	do.
Odessa	do.	do.
Pernau	?	1911
Dutch	?	do.
Russia	Russia	1896
Belgium	do.	do.
Riga	do.	do.
Minami	Hokkaido Imp. Univ.	1902

IV. Method of the experiment

The sick soil used in the present experiments was obtained from a field upon which flax had been cropped successively for more than thirty years. On this sick soil the wilt disease occurred severely at the seedling stage of the flax plants. The flax plants for experiments were raised in WAGNER's pots or tin cans of 16 cm. diameter and 18 cm. depth. Each pot was filled up with equal amounts of soil and the water supplying power of the soil was tested by LIVINGSTON's soil point to examine the soil moisture of each pot. Data for two examples of soil moisture regulated by the help of this apparatus are shown in Tables 2 and 3.

The soil temperature was controlled by means of a soil temperature tank (cf. Plate I). In some cases desiring to regulate the soil temperature lower than room temperature, the writer accomplished the purpose by aid of applying cool underground water. The apparatus for the experiment having been set up in a glass-house, the environmental conditions for the cultivation of the plants could be arbitrarily controlled and kept constant (cf. Plate II). In order to minimize experimental errors, different varieties for comparison were cultivated side by side in separate halves of the same pot. Consequently, the plants for comparison were cultivated under almost exactly similar environmental conditions.

Following TOCHINAI's (1920a) report, the seeds were sterilized by soaking in 0.1% aqueous solution of mercuric bichloride to prevent the outbreak of diseases caused by *Colletortrichum Lini* (WESTERDIJK) TOCHINAI and other seed-borne parasites.

In some of the experiments water culture was used. According to the result of the writer's study (1933), proper hydrogen ion concentration of the cultural solution for growth of flax being pH 4.0–5.5, to keep the solution at about pH 4.5 the following composition of nutrient salts was adopted:

NaH_2PO_4 1/5 mol solution	496.00 cc
Na_2HPO_4 „	4.00
Knop solution	500.00
Total amount	1000.00
H-ion concentration	pH 4.5

TABLE 2. The soil moisture regulated by the Livingston's auto-irrigator.[1]

(Observation in Exp. No. 2 in Chapter VI)

Height of the mercury column of the apparatus in cm.	Water content (% in dry weight)[2]					Water supplying power (% in dry weight)[3]			
	Date of observation				Average	Date of observation			Average
	Oct. 7	Oct. 16	Oct. 21	Oct. 26		Oct. 16	Oct. 21	Oct. 26	
7.5	34.08	35.14	35.13	35.80	35.03	2.59	2.78	2.43	2.60
4.0	41.30	41.95	42.99	43.01	42.31	4.53	4.47	4.85	4.61
3.0	44.55	44.18	43.67	43.77	44.04	5.19	5.15	5.47	5.27
1.0	55.67	57.63	57.26	55.06	56.40	5.75	5.73	5.76	5.74
0.0	56.59	58.13	56.55	55.10	56.59	5.82	5.74	5.81	5.79

(1) All figures denote the arithmetic mean value of actual measurement for every four pots.

(2) Water content was measured at the depth of 5~8 cm. under soil surface.

(3) The water supplying power was measured at 30 minutes exactly after insertion of the soil point into the soil.

TABLE 3. The soil moisture regulated by Livingston's auto-irrigator.[4]

(Observation in Exp. No. 3 in Chapter VI)

Height of the mercury column of the apparatus in cm.	Water content (% in dry weight)			Water supplying power (% in dry weight)		
	Date of observation		Average	Date of observation		Average
	Nov. 1	Nov. 8		Nov. 1	Nov. 8	
10.0	23.32	23.57	23.45	0.61	0.65	0.63
5.0	26.11	24.82	25.46	2.66	2.23	2.45
2.0	31.48	31.81	31.64	5.69	5.65	5.67
0.0	37.96	38.20	38.06	5.97	5.99	5.98

(4) All figures denote the arithmetic mean value of actual measurement for every six pots.

V. Comparative studies of some morphological characters of Minami and Riga varieties

As the initial examination of the present investigations, the writer made comparative observations about some morphological characters in order to examine the characteristics of Minami variety corresponding to those of the original variety Riga.

(1) Comparison of characteristics of seeds.

The seeds of Minami variety and Riga variety were examined in comparison of the following characters: (a) size, (b) weight, (c) construction, and (d) colour of the seed coat.

The flax seed has a pointed egg shape and is flat. The length, width and thickness of 50 seeds were measured by a micrometer and the weight of 1000 seeds was examined. Concerning the construction of the seeds, the thicknesses of epidermis, inner seed-coat, endosperm and cotyledon were measured under a microscope in cross sections through the widest part of them by glycerine mounting. The colour of the seed coat was judged by MUNSCHEL'S colour standard. The results of the observation were as follows:

TABLE 4. Size, weight and colour of seeds.

Variety	Size of seed (mean value of 50 seeds)			Weight of 1000 grains (gr)	Colour tone of seed coat
	Length (m.m.)	Width (m.m.)	Thickness (m.m.)		
Minami	3.576±0.080	1.943±0.097	0.801±0.012	3.434	VR (Reddish brown)
Riga	4.037±0.055	2.153±0.041	0.872±0.04	4.486	YR (Brown)

TABLE 5. The thickness of epidermis and the inner structures of seed. (Mean value of 20 seeds).

Variety	Thickness of			
	epidermis (μ)	inner seed coat (μ)	endosperm (μ)	cotyledon (μ)
Minami	3.77	2.82	11.72	34.41
Riga	5.23	3.28	11.34	35.61

As shown in the above tables, seeds of Minami variety are smaller than those of Riga and also thinner in construction, with the exception of the thickness of the endosperm. The colour difference of seed coat is quite remarkable and it is one of the important characteristics to distinguish the two varieties.

(2) Comparison of external morphological characters of seedlings.

To compare the morphological characters of the seedlings, the seeds of the two varieties were sown in the same pot and raised at room temperature of 18–22°C., and after 22 days the length of stem, the length of hypocotyl, the size of cotyledon and the length of the internode between the first leaf and cotyledons were measured. The results of the measurements are as follows:

TABLE 6. Some morphological characters of seedlings at 22 days after germination.

(Mean value of 50 individuals).

Variety	Length of stem (1) (in cm.)	Length of hypocotyl (in cm.)	Length of the internode between the first leaf and the cotyledon (in cm.)	Size of cotyledon	
				Length (in cm.)	Width (in cm.)
Minami	8.83	5.30	3.79	1.33	0.73
Riga	6.96	4.76	2.43	1.42	0.84

As shown in the above table, Minami variety is larger than Riga in every measurement with an exception of the size of cotyledons. Also in appearance of cotyledons, Riga variety shows plane surface while Minami variety shows crooked or curved appearance (cf. Plate III). These are remarkable characteristics of Minami variety to be distinguished from its original variety Riga.

(3) Comparative observation on the stomatal construction.

For the two varieties under consideration the number of stomata was compared by counting them in a unit surface area of cotyledons and epidermis of hypocotyl, but there was no difference

between the two varieties. In the number of bordering cells of stomata, however, there was an observable tendency for them to be more numerous in Minami variety than in Riga as shown in the following table.

TABLE 7. Comparison of numbers of bordering cells in stomatal construction.

Variety	Number of bordering cells			
	3	4	5	6
Minami	1	28	53	11
Riga	4	48	23	1

As is shown in the above table, in Minami variety stomata with 5 bordering cells occurred most frequently followed by cases having 4, 6, and 3 bordering cells in order, while in Riga variety the stomata with 4 bordering cells occurred most frequently followed by the cases having 5, 3 and 6 bordering cells in order. This is one of the different morphological characters distinguishing Minami variety from Riga.

(4) Comparative observation of growth.

In order to examine whether Minami variety shows any peculiarity in growth, comparative studies were made between this and Riga and thirteen other varieties in green-house and in field. Plants were cultured in pots, and all pots were treated under as nearly as possible identical conditions. The soil in the pots was taken from the field on which flax had never been cultivated to avoid the contamination of wilt fungus. In each pot seedlings of Minami and one of each of the other varieties were raised side by side (cf. Plates IV & V). The space for growing given to each individual was 2.5 cm. square. The water content of the pot soil was kept approximately ca. 45% by supplying to each pot the lost amount of water as indicated by weighing every morning and evening. The seeds were sown on 25 May and were harvested on 5 August 1933. The fibre percentage (the percentage of the total

fibre in whole stems) was examined in the harvested stems. The results of this examination are given in Table 8.

TABLE 8. Comparison of length, diameter, weight and fibre percentage of stem among Minami and 14 other flax varieties.(1)

Variety	In greenhouse					In field				
	Length of stem(2) (in c.m.)	Fresh weight of stem(3) (in gr.)	Available length of stem(4) (in cm.)	Diameter of stem(5) (in mm.)	Fibre %-tage(6)	Length of stem(2) (in cm.)	Fresh weight of stem(3) (in gr.)	Available length of stem(4) (in cm.)	Diameter of stem(5) (in mm.)	Fibre %-tage(6)
Minami	90.01	1.188	79.83	0.726	19.547	77.96	0.761	56.39	0.727	21.080
Ichigoshu	70.41	0.893	57.48	0.644	23.372	61.79	0.521	50.23	0.615	23.721
Chokeishu	67.51	0.921	55.76	0.679	21.494	56.56	0.605	44.89	0.681	20.627
Indoshu	76.05	1.020	69.08	0.737	22.162	64.65	0.616	46.35	0.741	21.491
Shinkokuama	71.74	0.973	62.36	0.701	21.325	54.69	0.557	43.66	0.709	20.963
Hokkaido zairaishu	68.82	1.082	66.47	0.754	19 950	58.79	0.650	45.28	0.699	20.968
Belgium	69.68	1.004	61.35	0.716	21.870	58.60	0.650	48.25	0.664	20.239
Pernau	75.49	1.031	64.03	0.775	19.035	55.43	0.662	46.90	0.659	19.308
France	68.31	0.933	63.85	0.716	20.822	67.21	0.522	45.72	0.635	22.691
Odessa	72.41	1.100	63.71	0.722	18.697	54.61	0.594	38.55	0.720	21.918
Riga	71.01	1.059	62.57	0.686	16.260	55.37	0.484	46.32	0.642	21.258
Holland	83.24	1.200	73.42	0.758	21.593	71.96	0.800	54.62	0.809	18.939
Russia	71.69	1.052	60.95	0.732	20.532	52.28	0.587	43.00	0.671	22.068
London	55.18	0.978	48.22	0.770	19.480	48.72	0.619	39.56	0.733	20.411
Dutch	69.08	1.000	60.72	0.671	19.628	68.05	0.779	50.93	0.772	21.666

(1) Seeds were sowed on 25 May and harvested on 1 August 1933.

(2), (3), (4) and (5) are each the mean values of actual measurement on 100 individuals.

(6) is measured by the dry weight and is the mean value of 20 individuals.

(4) is the stem length from cotyledon to the first branching point.

As shown in the above table the stem length of Minami variety is clearly longer than that of any other varieties, and the fresh weight of stem is also generally greater than the others, either in green house or in field. The fibre percentage of Minami variety

however, is intermediate comparing with the other varieties. In these results some special characteristics of Minami variety are recognized.

(5) Comparative observations of the root-structure.

As infection of *Fusarium Lini* occurs mostly on the root system of flax seedlings, the construction of root tissues may have important connection with the occurrence of the wilt disease. With this point in mind comparative studies of some morphological characters of the roots were carried out between Minami and Riga varieties. The plants were cultured side by side in the same pot, and the thickness of epidermis, width of epidermal cells and number of epidermal cells in certain unit arc (131.5 μ long) of epidermis in the cross section of the roots were observed.

Besides, the forms of root-hairs were examined with seedlings germinated in a Petri dish at 25°C. in a thermostat. Of the length and the form of the root hairs the writer could not find any distinction but of the thickness of them he obtained some different data between these varieties. The data obtained in the present experiments are shown in the following two tables.

TABLE 9. Comparison between varieties Minami and Riga in diameter of root hairs.

Variety	Diameter (μ)													Average diameter (μ)	Total number of observations
	11	12	13	14	15	16	17	18	19	20	21	22	23		
Variants in Minami(1)	—	4	3	5	15	10	11	5	10	7	5	2	—	16.857	77
Variants in Riga(1)	2	8	5	13	11	10	13	5	4	2	—	—	—	15.301	73

(1) Ten root hairs per individual were measured and their arithmetic mean values were arranged in classes.

From the results obtained in these experiments it is concluded that Minami variety is distinguished from Riga variety in some features of the root system. Epidermis is thinner but epidermal cells are larger and root hairs are thicker in the roots of Minami variety. The number of cells in a unit arc of the root cross section

is less in Minami variety than in Riga. However, it is quite uncertain whether and what meaning these morphological differences may have in connection with wilt resistance.

TABLE 10. Comparison of epidermal construction of root between varieties Minami and Riga.(1)

Individual number	Width of epidermal cells (μ)		Thickness of epidermis (μ)		Density of epidermal cells in cross section(2)	
	Minami	Riga	Minami	Riga	Minami	Riga
1	17.5	17.5	13.2	19.5	7.6	8.7
2	21.1	19.0	15.1	17.4	7.7	8.2
3	20.0	18.1	14.7	16.1	8.5	8.5
4	18.2	16.4	13.8	14.4	7.0	8.3
5	21.6	16.9	14.0	15.5	7.9	8.3
mean	19.7	17.6	14.2	16.6	7.7	8.5

(1) 10 cross sections of root per individual (just below the hypocotyl) were examined and every figure shows the arithmetic mean value of actual measurements of 20 cells respectively.

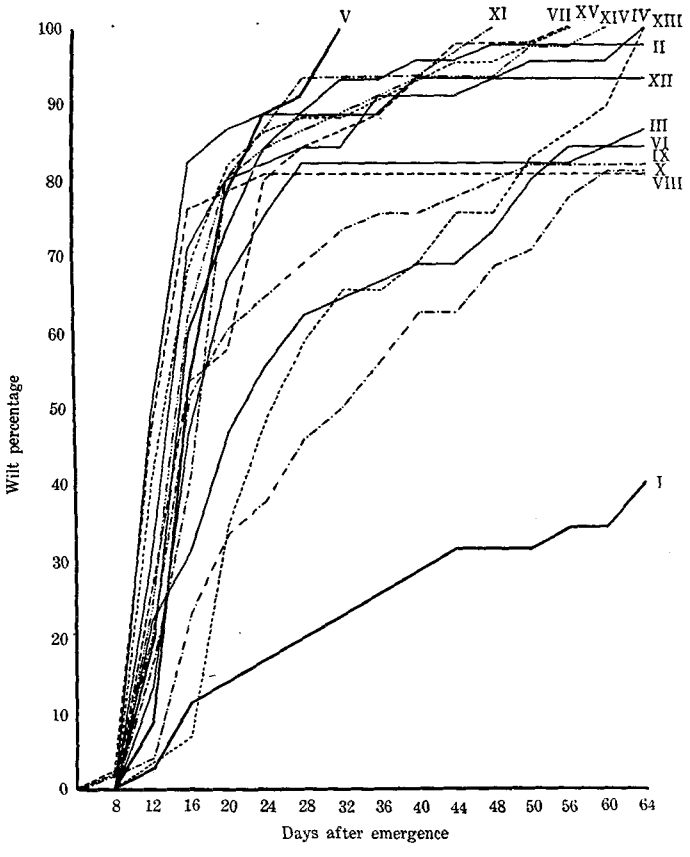
(2) Mean number of the epidermal cells counted in 131.5 μ arc of epidermis in cross section.

VI. Comparative experiments on the wilt resistance between Minami and several susceptible varieties of flax

It has already been recognized by TOCHINAI (1920a) that there is in Minami variety not only the strong wilt resistance but also an enduring character against the possible toxic principles accumulated in flax sick soil. The late Prof. Emer. MINAMI (1929) also reported that this variety showed a strong resistance to the wilt disease in the process of its cultivation for breeding. The writer, in order to make clear the degree of the wilt resistance of this variety carried out comparative experiments under greenhouse and field conditions between Minami variety and Riga and thirteen other important varieties, all being cultivated in the experimental farm of the Faculty of Aguriculture of the Hokkaido Imperial University.

(1) Experiments in a greenhouse.

The sick soil used in the experiments was supplied from the field successively cropped in flax for over 30 years. The sick soil was taken in unglazed pots, and from 15 to 26 grains of flax seeds were sown in each one. The soil moisture of every pot was kept at nearly 45% by the help of LIVINGSTON's auto-irrigator. This was ascertained to be the optimum soil moisture for the occurrence



Text-fig. I. Curves showing the wilt percentage with respect to 15 varieties of flax.

I...Minami. II...Chokeishu. III...Russia. IV...Hokkaido zairaishu. V...Riga. VI...Ichigoshu. VII...Indo. VIII...France. IX...Belgium. X...Shinkokuama. XI...London. XII...Pernau. XIII...Holland. XIV...Dutch. XV...Odessa.

TABLE 11. Results of observations on the occurrence of the wilt with respect to the resistant variety Minami and 14 susceptible varieties on sick soil under greenhouse conditions.(1)

Plot number	Variety	Total number of individuals	Number of wilted seedlings (A) & %-tage of the wilted to total plants (B)	Days after emergence														
				8	12	16	20	24	28	32	36	40	44	48	52	56	60	64
I	Minami	35	A	0	1	4	5	6	7	8	9	10	11	11	11	12	12	14
			B	0	2.86	11.42	14.29	17.14	20.00	22.86	25.71	28.57	31.43	31.43	31.43	34 29	34.29	40.00
II	Chokeishu	45	A	0	22	37	39	40	40	42	42	43	43	44	44	44	44	44
			B	0	48.89	82.22	86.67	88.89	88.89	93.33	93.33	95.56	95.56	97.78	97.78	97.78	97.78	97.78
III	Russia	45	A	0	6	21	30	34	37	37	37	37	37	37	37	37	38	39
			B	0	13.33	46.67	66.67	75.56	82.22	82.22	82.22	82.22	82.22	82.22	82.22	82.22	84.44	86.67
IV	Hokkaido zairaishu	45	A	0	14	32	36	37	38	38	41	41	41	42	43	43	43	45
			B	0	31.11	71.11	80.00	82.22	84.44	84.44	91.11	91.11	91.11	93.33	95.56	95.56	95.56	100.00
V	Riga	45	A	0	4	24	35	40	41	45								
			B	0	8.89	53.33	77.78	88.89	91.11	100.00								
VI	Ichigoshu	45	A	0	10	14	21	25	28	29	30	31	31	33	36	38	38	38
			B	0	22.22	31.11	46.67	55.56	62.22	64.44	66.67	68.89	68.89	73.33	80.00	84.44	84.44	84.44
VII	Indoshu	45	A	0	12	24	26	36	38	39	40	42	44	44	44	45		
			B	0	26.67	53.33	57.78	80.00	84.44	86.67	88.89	93.33	97.78	97.78	97.78	100.00		
VIII	France	42	A	1	20	32	33	34	34	34	34	34	34	34	34	34	34	34
			B	2.38	47.62	76.19	78.57	80.95	80.95	80.95	80.95	80 95	80.95	80.95	80.95	80.95	80.95	80.95
IX	Belgium	45	A	1	9	23	27	29	31	33	34	34	35	36	37	37	37	37
			B	2.22	20.00	51.11	60.00	64.44	68.89	73.33	75.56	75.56	77.78	80.00	82.22	82.22	82.22	82.22
X	Shinkokuama	48	A	1	2	11	16	18	22	24	27	30	30	33	34	37	39	39
			B	2.08	4.17	22.92	33.33	37.50	45.83	50.00	56.25	62.50	62.50	68.75	70.83	77.08	81.25	81.25
XI	London	30	A	0	5	12	24	26	28	28	28	28	29	30				
			B	0	16.67	40.00	80.00	86.67	93.33	93.33	93.33	93.33	96.67	100.00				
XII	Pernau	45	A	0	9	27	33	38	40	40	40	42	42	42	42	42	42	42
			B	0	20.00	60.00	73.33	84.44	88.89	88.89	88.89	93.33	93.33	93.33	93.33	93.33	93.33	93.33
XIII	Holland	29	A	0	1	2	10	14	17	19	19	20	22	22	24	25	26	29
			B	0	3.45	6.90	34.48	48.28	58.62	65.52	65.52	68.97	75.86	75.86	82.76	86.21	89.66	100.00
XIV	Dutch	45	A	0	11	28	36	38	39	40	41	42	42	42	44	44	45	
			B	0	24.44	62.20	80.00	84.44	86.67	88.89	91.11	93.33	93.33	93.33	97.78	97.78	100.00	
XV	Odessa	44	A	0	18	30	36	38	39	39	40	41	42	42	43	44		
			B	0	40.91	68.18	81.82	86.36	88.64	88.64	90.91	93.18	95.45	95.45	97.73	100.00		

(1) Temperature ranges were 16°C. to 26°C. at day and were 15°C. and to 22°C. at night.

of the wilt by the writer's preliminary experiments. The soil temperature of the pots varied from 16° to 26°C. The seeds were sterilized with 0.1% solution of mercuric bichloride before sowing to prevent the infection caused by seed-borne *Fusarium Lini* BOLLEY and *Colletotrichum Lini* (Westerkijk) TOCHINAI. Germination started after four days from the sowing, and within a few days the wilt could be observed. The data obtained by the external observations on the occurrence of the wilt are shown in Table 11 and Text Fig. I.

In these experiments it was clearly observed that the appearance of wilt symptoms reached its utmost severity after 20 to 24 days from the emergence of the seedlings. As seen in the table, Minami variety showed strong resistance to the wilt disease, and the percentage of wilted seedlings to total plants remained only 17% on the 24th day after emergence. Variety Shinkokuama was fairly resistant with a wilt percentage of 37.5%, and variety Holland followed it with 48.2% wilted seedlings. But seedlings belonging to all other varieties were susceptible to the wilt disease, with wilted seedlings on the 24th day after emergence exceeded 50%. On the 64th day, the end of the experiment, in Minami variety, the wilted seedlings were reckoned 40%, while those in the other varieties were higher than 80%, and in seven varieties, Hokkaidozairaishu, Riga, Indoshu, London, Holland, Dutch, and Odessa, which are generally cultivated in Hokkaido, the plants were annihilated. Especially RIGA variety was the highest in susceptibility, and the seedlings were annihilated after 32 days from the emergence. It is quite noteworthy that Minami variety which was selected from the highly wilt susceptible Riga variety, is extraordinarily resistant to the wilt disease in contrast to the mother variety Riga and other numerous flax varieties tested for comparison.

(2) Experiments in the field.

In order to compare the wilt resistance between Minami and Riga varieties under natural field conditions, experiments were carried out on sick soil in the experimental field successively cropped in flax. Two sections of 30 cm. square each were used for the two varieties, which were planted side by side in adjoining sections in one group. The growing space per plant was 2.5 cm. square. The

number of wilted seedlings was counted every day and the percentage of the wilted plants was calculated at the end of the 43 day experiment. The data obtained in this experiment are shown in the following table.

TABLE 12. Data obtained in the comparative experiments of wilt resistance between Minami and Riga varieties in the field of sick soil.

Variety	Plot	Total number of plants	Number of wilted plants	Percentage of the wilted	Average percentage of the wilted
Minami	Manured Plot 1	144	2	1.389	1.040
	Manured Plot 2	145	1	0.690	
	Non-manured Plot 1	148	32	22.297	28.971
	Non-manured Plot 2	202	72	35.644	
Riga	Manured Plot 1	113	81	71.681	79.223
	Manured Plat 2	116	108	86.765	
	Non-manured Plot 1	152	151	99.342	95.648
	Non-manured Plot 2	174	160	91.954	

The results obtained in these experiments indicated a stronger wilt resistance of Minami variety than of any other variety examined. In comparison of Minami variety and its mother variety Riga, the difference in percentage of wilted plants on the sick soil was quite striking. On non-manured plot it was 28% in Minami variety and 95% in Riga variety, while on manured plot it was only 1% in the former and 79% in the latter as an average. These differences were great enough to prove the peculiar resisting character of Minami variety to the wilt disease caused by *Fusarium Lini*. It is also conceivable that proper manuring of soil decreases the occurrence of the wilt disease, owing possibly to favoring the resistance of the host plant.

Thus Minami variety is excellent in the wilt resistant character and also in the vigor of growth as well as in available stem length

as shown in the foregoing experiments. But, it is really regrettable that the fibre productivity of this variety is intolerably meagre so that it cannot be economically cultivated as a fibre material. Further improvement in this point in indispensable before this variety can be brought into practical use. From another point of view, it is evident that this variety will be quite useful as a resistant parent in breeding of flax plants. Before carrying out actual breeding work, however, it is quite desirable to study and clarify the fundamental characters connected with the wilt resistance in Minami variety. For this purpose the writer proceeded with further studies on the physiological characters of Minami variety possibly to throw light on this problem.

VII. Studies on the influence of soil moisture upon the wilt resistance of flax

(1) Historical sketch of some studies on the influence of soil moisture on plant disease.

Soil moisture has important relation to the outbreak of some diseases. Especially in case of plant diseases caused by an attack of pathogenes in the soil, the soil moisture has a direct relation to the vitality and infecting power of the pathogenes, and on the other hand it affects the water supply to the host plants. In these connections the occurrence of the disease is greatly affected by the amount of moisture in the soil. Heretofore, there have been many reports of physiological studies on the relationship between soil moisture and the occurrence of diseases, but there is none of a study with respect to the flax wilt on the same line.

BURKHOLDER (1919) observed in the case of wilt disease of beans caused by *Fusarium marti-phaseoli* Burkh. that in dry weather it damaged really 50% of plants, but only 10% in wet weather. Then he (1920, 1924) carried out inoculation experiments under the conditions of regulated soil moisture. Seedlings of bean growing at different soil moistures ranging from 33.5%–60% of the water holding capacity of the soil were inoculated with suspensions of the conidia, and he concluded from the results of the experiment that the damage by this disease was great at low soil moisture.

TISDALE (1923) studied the wilting of cabbage seedlings caused by *Fusarium conglutinans* Wr. on a cabbage sick soil at regulated soil moisture and optimum soil temperature for the occurrence of the disease. In his experiments on the soil of 46% water holding capacity the results showed that at a 15% soil moisture the cabbage seedlings were killed most quickly and most badly having been annihilated on the 20th day, at 19% soil moisture the wilt appeared somewhat slowly, and at 23%, 26%, 64% and 68% soil moistures the wilt decreased little by little in order.

However, CLAYTON (1923b), who studied the wilt disease of tomato caused by *Fusarium Lycopersici* Sacc., recognized that at a low soil moisture such as 13–19%, or at saturated condition at 35%, the wilt occurred very slightly or not at all although the growth of the plants was poor, but in other cases the occurrence of the disease became gradually severe at higher soil moistures. Then he concluded that an extremely small or a large amount of soil moisture hinders the growth of host plants as well as occurrence of the wilting at the same time, and the length, and the intensity of dry periods interfers with the development of the disease.

DICKSON (1923) studied about the wheat blight caused by *Gibberella Saubinetii* (Mont.) Sacc. and the correlation between the soil moisture and the soil temperature. He reported that in high soil temperatures the disease occurred even if there were differences in the soil moisture, but in low temperatures the percentage of the disease decreased in correlation with increase in the soil moisture.

Looking over the above information it seems that wilt diseases caused by Fusarium fungi generally occur strongly in low soil moisture. It is considered presumably that in cases of wilt diseases caused by Fusaria the appearance of wilt symptoms become remarkable as a result of the shortage of water supply. Therefore in the case of low moisture content in soil, the increase of wilt appearance should result. Moreover, the low soil moisture inevitably results in the better aeration in soil, and the decrease of soil moisture in some extent might be a favorable condition for the development of aerobic Fusarium fungi, but on the contrary in many cases of plant disease, they occurred more strongly in high soil moisture condition.

Similar to the above cases, the flax caused by *Fusarium Lini* may be expected to become somewhat more remarkable in cases of low soil moisture content.

(2) Experiments.

The writer carried out some experiments to examine the influences of soil moisture upon the occurrence of the flax wilt disease and also upon the wilt-resistance in comparison of Minami and Riga varieties.

Experiment No. 1.

The experiments were carried out by means of pot cultures with the flax sick soil already described. The soil moistures were regulated at ca. 23%, ca. 25%, ca. 31% and ca. 38% by the help of LIVINGSTON's auto-irrigators. One week after pots were prepared, from 47 to 50 seeds per pot were sown. Groups of three pots were used for each of the different varieties and for different soil moistures. Atmospheric temperature in the green-house ranged from 25° to 27°C. and soil temperature was regulated from 23° to 25°C. during the experiment.

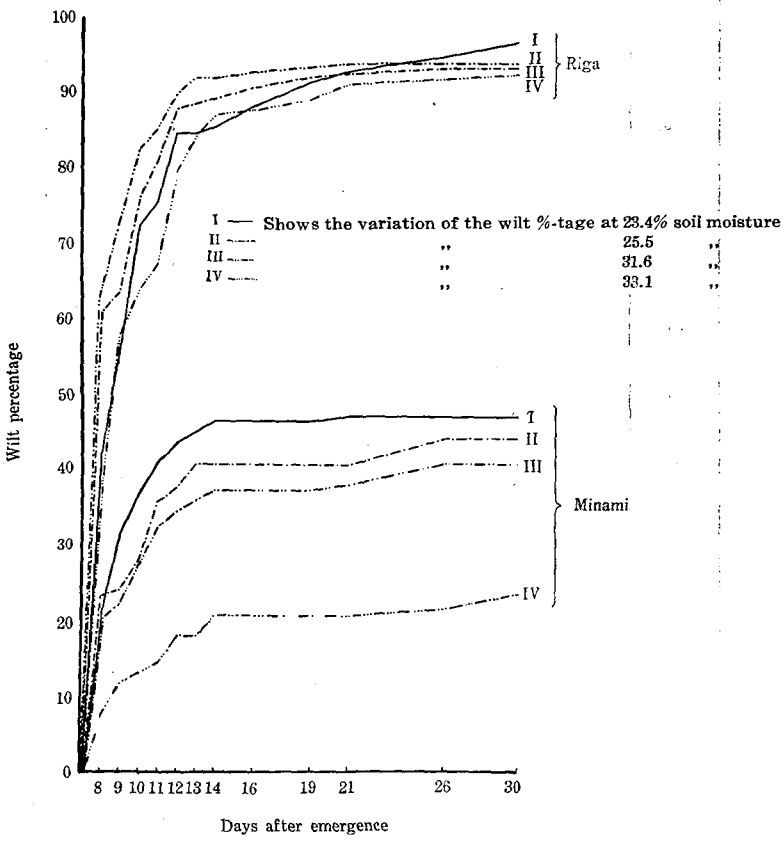
These are about the optimum temperatures for occurrence of the flax-wilt. The wilt occurred first on the 6th or 7th day after the emergence of the seedlings. Daily observations were continued from the 8th to the 30th day after the emergence. The data are given in Table 13 and summarized in Text Fig. II. (cf. Plate VI & VII)

Experiment No. 2.

In this experiment soil moistures were controlled at ca. 35%, ca. 42%, ca. 44%, ca. 55% and ca. 57% respectively. Two pots in each case were used for different varieties and for different soil moistures. Soil temperature was kept from 18° to 21°C. during the experiment. From 45 to 50 grains of the seeds of each variety per pot were sown, and the seedling emerged on the 4th day after sowing. The symptoms of the wilt disease appeared on the 8th or 9th after the emergence of the seedings. Daily observations of wilted plants were continued from the 8th to the 31st day after the

TABLE 13. Observed results of occurrence of the wilting in comparison of Minami and Riga varieties on the sick soil with different soil moisture.

Plot	Soil moisture in %	Variety	Total number of emerged individuals	Daily number of the wilted individuals (A), daily total of the wilted individuals (B) & %-tage of the wilted (C)	Days after emergence											
					8	9	10	11	12	13	14	16	19	21	26	30
I	23.4	Minami	146	A	31	15	8	6	4	2	2	0	0	1	0	0
				B	31	46	54	60	64	66	68	68	68	69	69	69
				C	21.23	31.51	36.99	41.10	43.84	45.21	46.58	46.58	46.58	47.26	47.26	47.26
		Riga	151	A	64	20	25	5	14	0	1	4	5	2	3	3
				B	64	84	109	114	128	128	129	133	138	140	143	146
				C	42.38	55.63	72.19	75.50	84.77	84.77	85.43	88.07	91.39	92.71	94.70	96.69
II	25.5	Minami	145	A	34	1	6	11	3	4	0	0	0	0	5	0
				B	34	35	41	52	55	59	59	59	59	59	64	64
				C	23.44	24.13	28.27	35.86	37.93	40.68	40.68	40.68	40.68	40.68	44.13	44.13
		Riga	148	A	90	4	18	8	10	1	1	2	2	1	1	0
				B	90	94	112	120	130	131	132	134	136	137	138	138
				C	60.81	63.51	75.67	81.08	87.83	88.51	89.18	90.54	91.89	92.56	93.24	93.24
III	31.6	Minami	147	A	30	3	8	7	3	2	2	0	0	1	4	0
				B	30	33	41	48	51	53	55	55	55	56	60	60
				C	20.40	22.44	27.89	32.65	34.69	36.05	37.41	37.41	37.41	38.09	40.81	40.81
		Riga	147	A	93	14	14	4	7	3	0	1	1	1	0	0
				B	93	107	121	125	132	135	135	136	137	138	138	138
				C	63.26	72.78	82.31	85.03	89.79	91.83	91.83	92.51	93.19	93.87	93.87	93.87
IV	38.1	Minami	144	A	11	6	2	2	5	0	4	0	0	0	1	3
				B	11	17	19	21	26	26	30	30	30	30	31	34
				C	7.63	11.80	13.19	14.58	18.05	18.05	20 83	20.83	20.83	20.83	21.52	23.61
		Riga	146	A	56	28	9	5	18	7	4	1	2	3	1	1
				B	56	84	93	98	116	123	127	128	130	133	134	135
				C	38.35	57.53	63.69	67.12	79.45	84.24	86.98	87.67	89.04	91.09	91.78	92.46

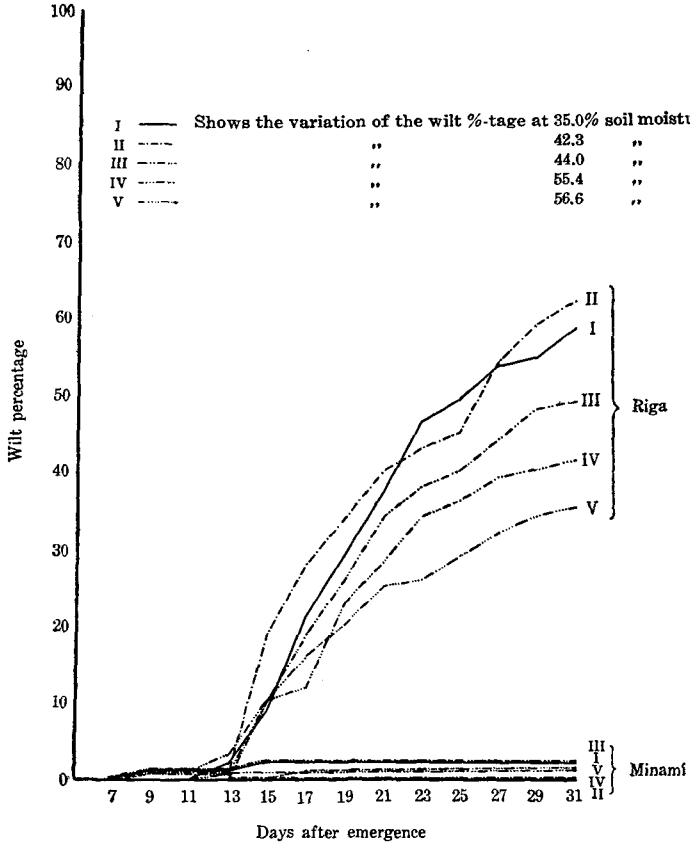


Text-fig. II. Curves showing the wilt percentage in Minami and Riga varieties with respect to different soil moisture.

emergence. The results of the observations are given in Table 14 and summarized in Text Fig. III.

TABLE 14. Observed results of occurrence of the wilting in comparison of Minami and Riga varieties on the sick soil with different soil moisture.

Plot	Soil moisture in %	Variety	Total number of emerged individuals	Daily number of the wilted individuals (A), daily total of the wilted individuals (B) & % tage of the wilted (C)	Days after emergence												
					7	9	11	13	15	17	19	21	23	25	27	28	31
I	35.0	Minami	95	A	0	1	0	0	1	0	0	0	0	0	0	0	0
				B	0	1	1	1	2	2	2	2	2	2	2	2	2
				C	0	1.05	1.05	1.05	2.11	2.11	2.11	2.11	2.11	2.11	2.11	2.11	2.11
		Riga	99	A	0	0	0	2	7	12	8	8	9	3	4	1	4
				B	0	0	0	2	9	21	29	37	46	49	53	54	58
				C	0	0	0	2.02	9.09	21.21	29.29	37.37	46.46	49.49	53.53	54.54	58.58
II	42.3	Minami	100	A	0	0	0	0	0	0	0	0	0	0	0	0	0
				B	0	0	0	0	0	0	0	0	0	0	0	0	0
				C	0	0	0	0	0	0	0	0	0	0	0	0	0
		Riga	100	A	0	1	0	0	18	9	6	6	3	2	9	5	3
				B	0	1	1	1	19	28	34	40	43	45	54	59	62
				C	0	1.00	1.00	1.00	19.00	28.00	34.00	40.00	43.00	45.00	54.00	59.00	62.00
III	44.0	Minami	91	A	0	1	0	0	1	0	0	0	0	0	0	0	0
				B	0	1	1	1	2	2	2	2	2	2	2	2	2
				C	0	1.10	1.10	1.10	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.20
		Riga	100	A	0	1	0	0	9	9	7	8	4	2	4	4	1
				B	0	1	1	1	10	19	26	34	38	40	44	48	49
				C	0	1.00	1.00	1.00	10.00	19.00	26.00	34.00	38.00	40.00	44.00	48.00	49.00
IV	55.4	Minami	95	A	0	0	0	1	0	0	0	0	0	0	0	0	0
				B	0	0	0	1	1	1	1	1	1	1	1	1	1
				C	0	0	0	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
		Riga	99	A	0	0	0	0	10	2	11	5	6	2	3	1	1
				B	0	0	0	0	10	12	23	28	34	36	39	40	41
				C	0	0	0	0	10.10	12.12	23.23	28.28	34.34	36.36	39.39	40.40	41.41
V	56.6	Minami	90	A	0	0	0	0	0	1	0	0	0	0	0	0	0
				B	0	0	0	0	0	1	1	1	1	1	1	1	1
				C	0	0	0	0	0	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
		Riga	99	A	0	0	0	2	7	6	4	5	1	3	3	2	1
				B	0	1	1	3	10	16	20	25	26	29	32	34	35
				C	0	1.01	1.01	3.03	10.10	16.16	20.20	25.25	26.26	29.29	32.32	34.34	35.35



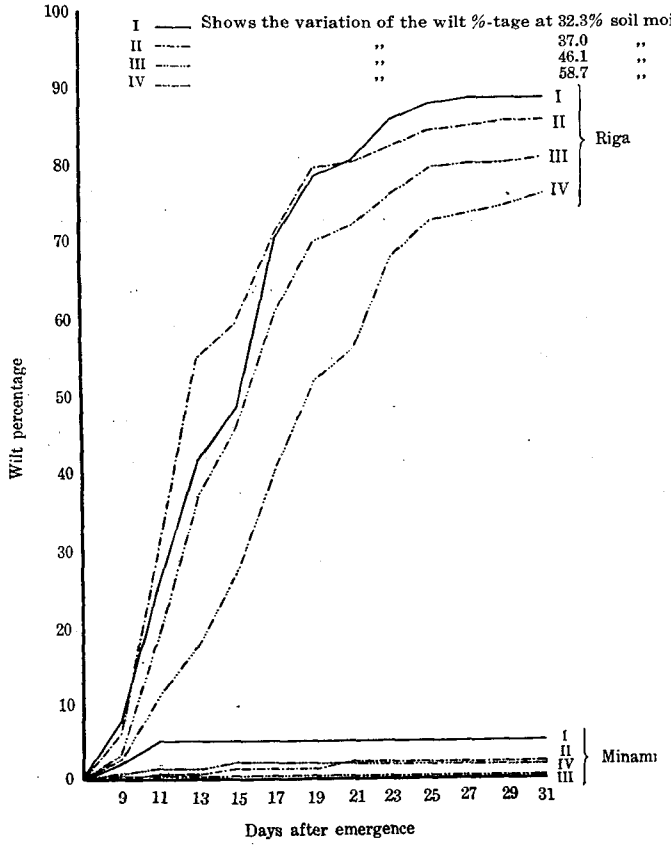
Text-fig. III. Curves showing the wilt percentage in Minami and Riga varieties with respect to different soil moisture.

Experiment No. 3.

In the present experiment the soil moistures were regulated at ca. 32%, ca. 37%, ca. 46% and ca. 59% respectively. Groups of 3 pots were used for each of the different varieties and of the different soil moistures. Atmospheric temperature of the greenhouse ranged from 23°C. to 27°C. and the soil temperature from 21°C. to 25°C. From 45 to 50 grains of seeds were sown per pot. On the 4th day after sowing the seedlings emerged, and the wilt first occurred on the 7th or 8th day after the emergence of the seedlings. The occurrence of the wilt was observed on every other day from the 9th to the 31st day after the emergence of the seedlings. The results are shown in Table 15 and are summarized in Text Fig. IV. (cf. Pl. VIII, IX & X)

TABLE 15. Observed results of occurrence of the wilt in comparison of Minami and Riga varieties on the sick soil with different soil moisture.

Plot	Soil moisture in %	Variety	Total number of emerged individuals	Daily number of the wilted individuals (A), daily total of the wilted individuals (B) & %-tage of the wilted (C)	Days after emergence											
					9	11	13	15	17	19	21	23	25	27	29	31
I	32.3	Minami	140	A	3	4	0	0	0	0	0	0	0	0	0	0
				B	3	7	7	7	7	7	7	7	7	7	7	7
				C	2.14	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
		Riga	147	A	11	26	24	10	30	14	3	8	3	1	0	0
				B	11	37	61	71	101	115	118	126	129	130	130	130
				C	7.48	25.17	41.49	48.29	70.06	78.23	80.27	85.71	87.75	88.43	88.43	88.43
II	37.0*	Minami	139	A	0	1	0	1	0	0	1	0	0	0	0	0
				B	0	1	1	2	2	2	3	3	3	3	3	3
				C	0	0.71	0.71	1.43	1.43	1.43	2.15	2.15	2.15	2.15	2.15	2.15
		Riga	159	A	9	36	37	7	17	13	1	3	3	1	1	0
				B	9	45	82	89	106	119	120	123	126	127	128	128
				C	6.00	30.00	54.66	59.33	70.66	79.33	80.00	82.00	84.00	84.66	85.33	85.33
III	46.1	Minami	144	A	1	0	0	0	0	0	0	0	0	0	0	0
				B	1	1	1	1	1	1	1	1	1	1	1	1
				C	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0 69	0.69	0.69
		Riga	149	A	5	23	27	13	22	14	3	6	5	0	0	1
				B	5	28	55	68	90	104	107	113	118	119	119	120
				C	3.35	18.79	36 91	45.63	60.40	69.79	71.81	75.83	79.19	79.86	79.86	80.53
IV	58.7	Minami	141	A	1	1	0	1	0	0	0	0	0	0	0	0
				B	1	2	2	3	3	3	3	3	3	3	3	3
				C	0.70	1.41	1.41	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12
		Riga	149	A	4	12	15	14	20	17	6	18	7	1	2	2
				B	4	16	26	40	60	77	83	101	108	109	111	113
				C	2.68	10.73	17.44	26.84	40.26	51.67	55.70	67.78	72.48	73.15	74.49	75.83



Text-fig. IV. Curves showing the wilt percentage in Minami and Riga varieties with respect to different soil moisture.

(3) General conclusions from the experimental results obtained in the present studies.

Glancing over the results obtained in the present experiments, Nos. 1, 2 and 3, it is easy to recognize that the occurrence of the wilt disease was varied according to the percentage of soil moisture and to the varieties of flax.

In the case of Minami variety in Exp. No. 1 (soil temperature 25°–27°C.), and of Riga variety in Experiments No. 2 (soil temperature 18°–21°C.) and No. 3 (soil temperature 21°–25°C.), it was clear that the percentage of wilted plants decreased gradually but certainly owing to the increase in soil moisture. These results

indicate that an increase of soil moisture probably retards the occurrance of the wilting of flax seedlings to a certain extent. However, in the case of Riga variety in Exp. No. 1, and of Minami variety in Exps. No. 2 and No. 3, the percentages of wilted plants ranged so narrowly as from ca. 93% to ca. 97%, from ca. 1% to 2% and from ca. 2% to 5% respectively. These results suggest almost negligibly slight influences of varying soil moisture on the occurrence of the wilt disease.

The reason why such a diversity in the occurrence of the wilt disease took place even at the soil moisture varying with similar trend may be the predominate influence of the soil temperatures which favored an outbreak of the wilt disease in regard to different varieties, especially on Minami or Riga variety. That is to say, the possible influences of varying soil moistures were practically overwhelmed by the wilt-promoting influence of soil temperatures. The relation of soil temperature to the occurrence of the wilt disease seems to be quite important as well as interesting, and it will be dwelt upon in the next section. In general, great differences in the percentages of the wilted plants occurred between Minami and Riga varieties possibly owing to their conspicuous difference in the wilt resistance, but the trend of decrease of the wilt due to increasing soil moisture was essentially homologous.

As a whole, it was concluded that soil moisture is one of the important physical factors of soil condition which hinders the occurrence of the wilt disease in flax plants, and that increases of soil moisture within a certain limit influence the occurrence of the wilt disease in favor of the host plant, although it is sometimes practically overwhelmed by wilt promoting influences of soil and atmospheric temperatures.

VIII. Studies on the influence of soil temperature upon the wilt resistance of flax

(1) Historical sketch of some studies on the influence of soil temperature on the flax wilt.

Since the studies of soil temperature in relation to the occurrence of plant diseases became a current problem in plant pathology thanks to the early efforts of Prof. L. R. JONES and his staff in the

University of Wisconsin, a great number of works along this line have been published up to the present time. Especially the contributions from the University of Wisconsin have been remarkable. In 1926 L. R. JONES, JAMES JOHNSON and JAMES G. DICKSON published a summarized report of their works. They distinguished the modes of influence of soil temperature upon the occurrence of diseases in three categories. First is the case when the optimum temperature for the growth of the causal fungus agrees with that for the utmost development of the disease at comparatively high temperature. Most of the wilt diseases caused by Fusaria belong to this category. The second is the case when the diseases predominate at comparatively low soil temperatures as in onion smut caused by *Tuburcinia Cepulae* (Frost) Liro (= *Urocystis Cepulae* Frost), tobacco root rot caused by *Thielavia basicola* (B. et C.) Zopf. and potato stem canker caused by *Rhizoctonia Solani* Kühn etc. In these first and second categories the influence of temperature upon germination and development of the fungi have fundamentality great significance. The third category is the case when the development of diseases caused by the same fungus on different host plants predominates at a high or a low soil temperature owing to their growth being either accelerated or retarded at those temperatures. The wilt-diseases of wheat and corn seedlings caused by the same fungus, *Gibberella saubinetii* (Mont.) Sacc., are very good examples. The reason why the wheat-wilt predominates at a high soil temperature and the corn-wilt does at a low one is that in the case of wheat seedlings the critical period of weak cell-membrane stage against the penetration of mycelium of the fungus can not pass rapidly at a high soil temperature, while it is quite the reverse in the case of corn-seedlings.

In the wilt disease of flax, interesting phenomena as to the relation between soil temperature and the occurrence of the wilt were observed experimentally by TISDALE (1917b). During his studies on the flax-wilt in a greenhouse of the University of Wisconsin (1915–1916) he noticed that the development of the wilt was strikingly varied by plants according to the distance from a heating coil. This fact suggested that soil temperature controls the occurrence of the flax-wilt. TISDALE (1916, 1917a) also concluded that the resistance of flax to the wilt is a relative character, as it is varied by environmental factors especially by temperature. Ac-

cording to his opinion, even a susceptible variety would show only a slight occurrence of wilting at low soil temperature. Concerning this problem, STOA (1920) noting in his field experiment on the flax wilt that the wilt is more destructive some seasons than others, stated that high temperatures increase the infecting power of the wilt fungus while low temperatures, or cool seasons, are not favorable to the wilt infection. He believed that the fungus does not thrive under these conditions, while on the other hand, the flax plants are more vigorous and productive at low temperatures. He, therefore, concluded that "conditions making for the optimum infecting power of the fungus are, in general, conditions that appear to lessen the resistance of the flax plant".

In 1922 L. R. JONES and W. B. TISDALE reported the soil temperature relation in the wilt disease of flax and said that the occurrence of the disease increased coordinately with the rise of soil temperature until its optimum at 24°–28°C. was reached, and the marginal soil temperatures for the occurrence of the wilt disease were 14°C. in minimum and 38°C. in maximum. They also said that the environmental conditions have close connection with resistance and susceptibility of flax plant to the wilt disease.

BARKER (1923) concluded in his studies on the resistance of flax to wilt that the wilt resistance of flax is a relative character. The plants have a predisposition to be more or less resistant to the attack of the pathogene, but at a high soil temperature the resistance deteriorates. On the other hand the pathogene is animated by favorable temperature condition, and consequently the wilt disease breaks out exceedingly. He has demonstrated clearly that the amount of wilt which develops in either a resistant or a susceptible strain may be very greatly affected by soil temperatures. When the flax plant was planted late in season at a high soil temperature, even a resistant variety may be injured severely by the wilt, and on the other hand, when flax was sown early in season at a low soil temperature, even a susceptible veriety can escape from an attack of the wilt and may produce a good crop.

The present writer carried out some experiments in order to examine how soil temperatures influence the wilt resistance of Minami variety in comparison with the susceptible Riga variety.

TABLE 16. Occurrence of the wilt at the different soil temperatures in Experiment No. 1.

Soil temp. (C.)	Variety	Total number of emerged individuals	Daily number of the wilted individuals (A), total number of the wilted individuals (B) & %-tage of the wilted (C)	Days after emergence									
				2	4	6	8	10	12	14	16	18	20
15°	Minami	58	A	0	0	0	0	0	2	1	2	1	1
			B	0	0	0	0	0	2	3	5	6	7
			C	0	0	0	0	0	3.45	5.17	8.62	10.34	12.07
	Riga	63	A	0	0	0	0	2	5	3	4	4	3
			B	0	0	0	0	2	7	10	14	18	21
			C	0	0	0	0	3.17	11.11	15.87	22.22	28.57	33.33
20°	Minami	53	A	0	0	0	1	1	2	1	3	2	1
			B	0	0	0	1	2	4	5	8	10	11
			C	0	0	0	1.89	3.77	7.55	9.43	15.09	18.87	20.75
	Riga	60	A	0	0	4	8	14	13	9	1	5	1
			B	0	0	4	12	26	39	48	49	54	55
			C	0	0	6.67	20.00	43.33	65.00	80.00	81.67	90.00	91.67
25°	Minami	60	A	0	1	0	5	2	4	2	4	4	3
			B	0	1	1	6	8	12	14	18	22	25
			C	0	1.66	1.66	10.00	13.33	20.00	23.33	30.00	36.66	41.67
	Riga	59	A	0	1	8	20	16	3	5	0	4	2
			B	0	1	9	29	45	48	53	53	57	59
			C	0	1.69	15.25	49.15	76.27	81.36	89.83	89 83	96.61	100.00
30°	Minami	50	A	0	1	5	17	11	4	4	4	3	1
			B	0	1	6	23	34	38	42	46	49	50
			C	0	2.00	12.00	46.00	68.00	76.00	84.00	92.00	98.00	100.00
	Riga	57	A	0	13	20	16	7	1				
			B	0	13	33	49	56	57				
			C	0	22.81	57.89	85.96	98.25	100.00				
35°	Minami	34	A	0	2	9	12	6	2	1	0	0	0
			B	0	2	11	23	29	31	32	32	32	32
			C	0	5.88	32.35	67.65	85.29	91.18	94.11	94.11	94.11	94.11
	Riga	50	A	0	4	17	5	9	5	2	1	2	0
			B	0	4	21	26	35	40	42	43	45	45
			C	0	8.00	42.00	52.00	70.00	80.00	84.00	86.00	90.00	90.00
40°	Minami	42	A	0	22	10	4	12	8	1	2	0	0
			B	0	2	12	16	28	36	37	39	39	39
			C	0	4.76	28.57	38.10	66.67	85.71	88.10	92.86	92.86	92.86
	Riga	55	A	0	4	10	10	5	9	1	3	2	0
			B	0	4	14	24	29	38	39	42	44	44
			C	0	7.27	25 45	43.64	52.73	69.09	70.91	76.36	80.00	80.00

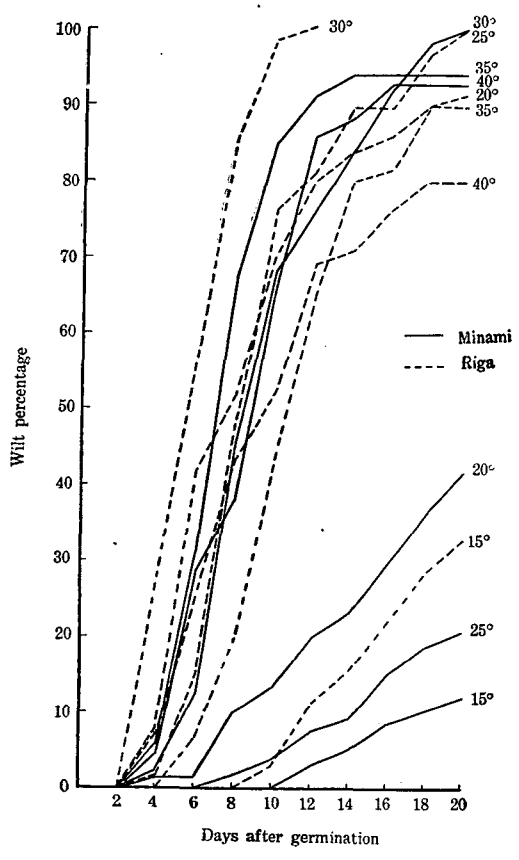
(2) Experiments.

The present experiments were carried out to examine the effects of soil temperature upon the resistance and susceptibility of Minami and Riga varieties to the wilt disease. As the infection source, sick soil was taken from the field successively cropped with flax. The experiments were carried out in a greenhouse. Soil moisture in every pot was regulated by the help of LIVINGSTON's auto-irrigators and their soil temperatures were regulated arbitrarily by means of soil temperature tanks. Daily fluctuations of the regulated soil temperature in a pot measured 1°–2°C. in summer and 3°–4°C. in winter due to the influence of varying atmospheric temperature in the greenhouse which ranged from 12°C. to 25°C. in winter and from 16°C. to 27°C. in summer. The soil temperatures lower than 20°C. were maintained by the aid of cool well-water led into the soil temperature tank. In the well having a depth of 50 feet underground, the water keeps at just 11°C. in all seasons. Using that water a uniform low soil temperature of 12°C. was realized.

Experiment No. 1.

The soil temperatures in this experiment were regulated at 15°, 20°, 25°, 30°, 35°, and 40°C., and the soil moisture of every pot was controlled at about 41%. Two pots each were used for every experimental plot. From 25 to 30 grains of sterilized seeds of Minami and Riga varieties were sown side by side in each half of a pot respectively. The seedlings generally emerged at 3 or 4 days after sowing. Daily observations on the occurrence of the wilt were continued 20 days from the emergence of the seedlings, and the percentages of wilted plants were calculated. The results are given in Table 16 and summarized in Text Fig. V.

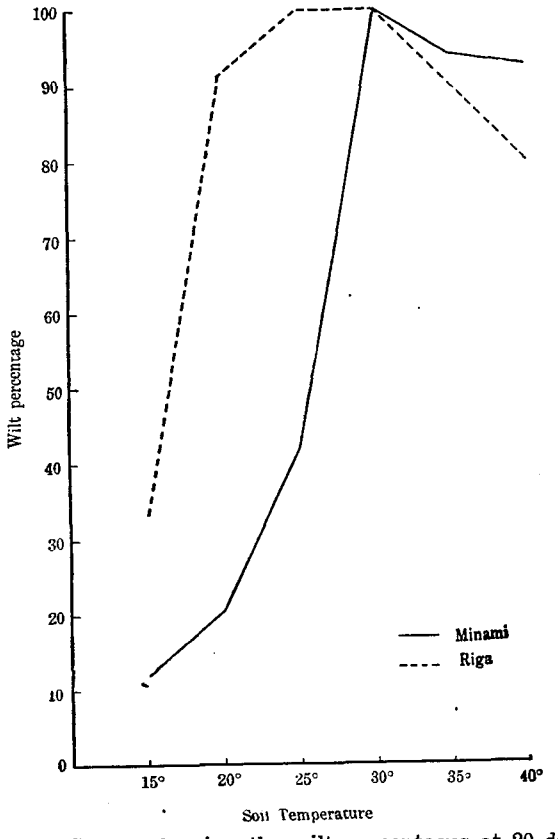
As shown in Table 16 and in Fig. V, in Minami variety the percentages of the wilted plants were 12%, 30%, 41%, 100%, 94% and 29% at 15°, 20°, 25°, 30°, 35° and 40°C. respectively. In Riga variety the percentages of wilted plants at the end of the experiments were 33% at 15°C., 91% at 20°C., 100% at 25°C., 100% at 30°C., 90% at 35°C. and 80% at 40°C. The wilt occurred most severely in both varieties at the soil temperature of 30°C. and all the seedlings were wilted as promptly as within 12 days after their



Text-fig. V. Curves showing the wilt percentages of Minami and Riga varieties with respect to different soil temperatures

emergence in Riga variety and within 20 days in Minami variety. In Riga variety the whole number of plants were annihilated within 20 days also at 25°C. It was an extremely remarkable contrast that the high wilt percentages occurred in Riga variety at 25°C., and lower soil temperatures and that far smaller percentages occurred in Minami variety. It was also noticeable that the decrease of wilt percentages at the temperature higher than 30°C. was more conspicuous in Riga variety than in Minami variety.

The contrast of occurrence of the wilt in Minami and in Riga varieties at the varying soil temperatures is shown quite distinctly by the curves in Text Fig. VI.

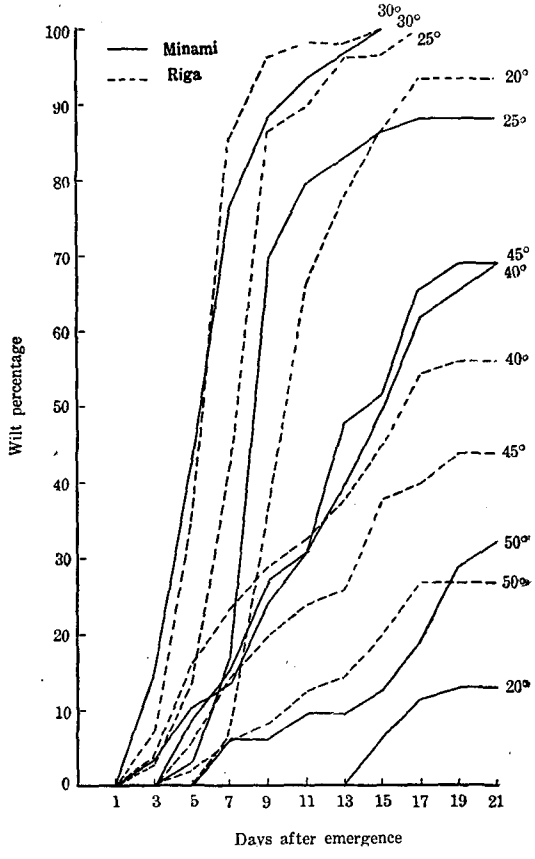


Text-fig. VI. Curves showing the wilt percentages at 20 days after emergence with respect to different soil temperatures.

Experiment No. 2.

In this experiment, the soil temperatures were regulated at 20°, 25°, 30°, 40°, 45° and 50°C., and the soil moisture of every pot was controlled at about 42%. Two pots each were used for every experimental plot. Thirty grains of sterilized seeds of Minami and Riga varieties were sown side by side in each half of a pot. The seedlings generally emerged 3 or 4 days after sowing. Daily observations on the occurrence of wilt were continued for 21 days after emergence of the seedlings, and the percentages of wilted plants were calculated. The data of this experiment are summarized in Table 17 and shown by curves in Text Figs. VII and VIII.

As shown in the above table, in Minami variety the wilt percentage remained at only 13.3% at 20°C. and 88.1% at 25°C. at the end of the experiment, but all the seedlings were killed by the wilt disease within 15 days at 30°C. On the other hand, in Riga variety the wilt percentage was as large as 93% even at 20°C. soil



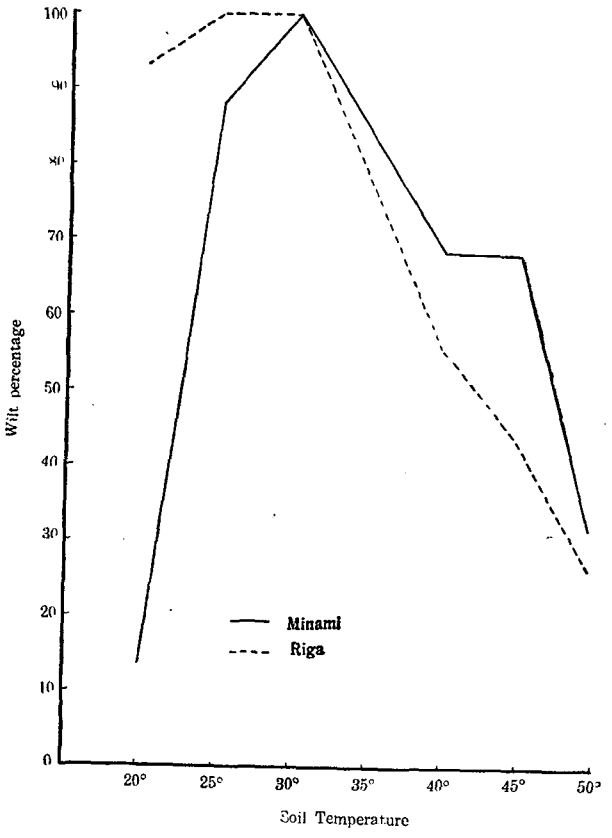
Text-fig. VII. Curves showing the wilt percentages of Minami and Riga varieties with respect to different soil temperatures.

temperature at the end of the experiment, and all the seedlings were annihilated within 17 days at 25°C. and within 15 days at 30°C. after their emergence. Above 30°C. the occurrence of the wilting decreased to 56% at 40°C. and 44% at 45°C. The results at 30°C. soil temperature were quite the same in either variety. At 40°C.

TABLE 17. Occurrence of the wilt at the different soil temperatures in Experiment No. 2.

Soil temp. (C.)	Variety	Total number of emerged individuals	Daily number of the wilted individuals (A), daily total of the wilted individuals (B) & %-tage of the wilted (C)	Days after emergence										
				1	3	5	7	9	11	13	15	17	19	21
20°	Minami	60	A	0	0	0	0	0	0	0	4	3	1	0
			B	0	0	0	0	0	0	0	4	7	8	8
			C	0	0	0	0	0	0	0	6.67	11.67	13.33	13.33
	Riga	59	A	0	0	0	4	18	17	17	5	4	0	0
			B	0	0	0	4	22	39	46	51	55	55	52
			C	0	0	0	6.78	37.29	66.10	77.97	86.44	93.22	93.22	93.22
25°	Minami	59	A	0	0	2	8	31	6	2	2	1	0	0
			B	0	0	2	10	41	47	49	51	52	55	52
			C	0	0	3.39	16.95	69.49	79.66	83.05	86.44	88.14	88.14	88.14
	Riga	59	A	0	2	6	17	26	2	4	0	2		
			B	0	2	8	25	51	53	57	57	59		
			C	0	3.39	13.56	42.37	86.44	89.83	96.61	96.61	100.00		
30°	Minami	59	A	0	9	16	20	7	3	2	2			
			B	0	9	25	45	52	55	57	59			
			C	0	15.25	42.37	76.27	88.14	93.22	96.61	100.00			
	Riga	57	A	0	4	16	29	6	1	0	1			
			B	0	4	20	49	55	56	56	57			
			C	0	7.02	35.09	85.96	96.49	98.25	98.25	100.00			
40°	Minami	58	A	0	0	5	4	7	2	5	6	7	2	2
			B	0	0	5	9	16	18	23	29	36	38	40
			C	0	0	8.62	15.52	27.59	31.03	39.66	50.00	62.07	65.52	68.96
	Riga	55	A	0	2	7	4	3	2	3	4	5	1	0
			B	0	2	9	13	16	18	21	25	30	31	31
			C	0	3.64	16.36	23.64	29.09	32.73	38.18	45.45	54.55	56.36	56.36
45°	Minami	58	A	0	2	4	2	6	4	10	2	8	2	0
			B	0	2	6	8	14	18	28	30	38	40	40
			C	0	3.45	10.34	13.79	24.14	31.03	48 28	51.72	65.52	68.97	68.97
	Riga	50	A	0	0	3	4	3	2	1	6	1	2	0
			B	0	0	3	7	10	12	13	19	20	22	22
			C	0	0	6.00	14.00	20.00	24.00	26.00	38.00	40.00	44.00	44.00
50°	Minami	31	A	0	0	0	2	0	1	0	1	2	3	1
			B	0	0	0	2	2	3	3	4	6	9	10
			C	0	0	0	6.45	6.45	9.68	9.68	12.90	19.35	29.03	32 26
	Riga	48	A	0	0	1	2	1	2	1	3	3	0	0
			B	0	0	1	3	4	6	7	10	13	13	13
			C	0	0	2.08	6.25	8.33	12.50	14.58	20.83	27.08	27.08	27.08

the wilt percentage in Minami variety at the end of the experiment was 69%, which in markedly higher than the 56.36% obtained in Riga variety. At 50°C., however, the occurrence of the wilting decreased conspicuously in either variety in almost equal manner.



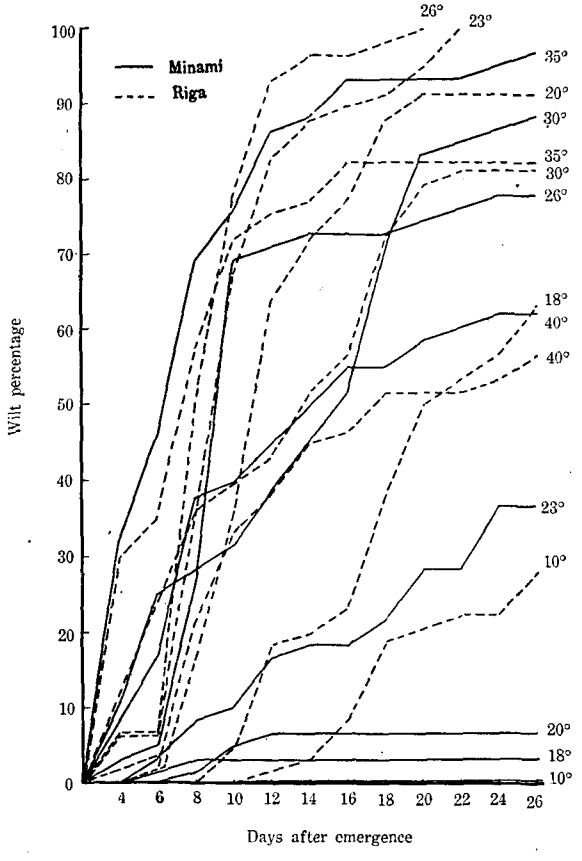
Text-fig. VIII. Curves showing the wilt percentages at 21 days after emergence with respect to different soil temperatures.

Curves in Text Fig. VIII show the comparison of the total wilt percentage of Minami and Riga varieties on the 21st day after emergence. In Minami variety the maximum wilt percentage was reached at 30°C., while in Riga variety it was reached at 25°C. and 30°C. Until these maxima were reached, the increases in the wilt percentages were quite similar in the cases of Exp. No. 1. Over 30°C., the decreases of the wilt percentages in both varieties were

conspicuous, and at 50°C. the wilt percentages of both varieties somewhat resembled each other, i. e. ca. 27% in Riga variety and ca. 32% in Minami. Thus it is considered that the activity of the causal fungus was unfavorably influenced by high soil temperature and as a result the occurrence of the wilt disease diminished notwithstanding the feeble growth of the flax plants.

Experiment No. 3.

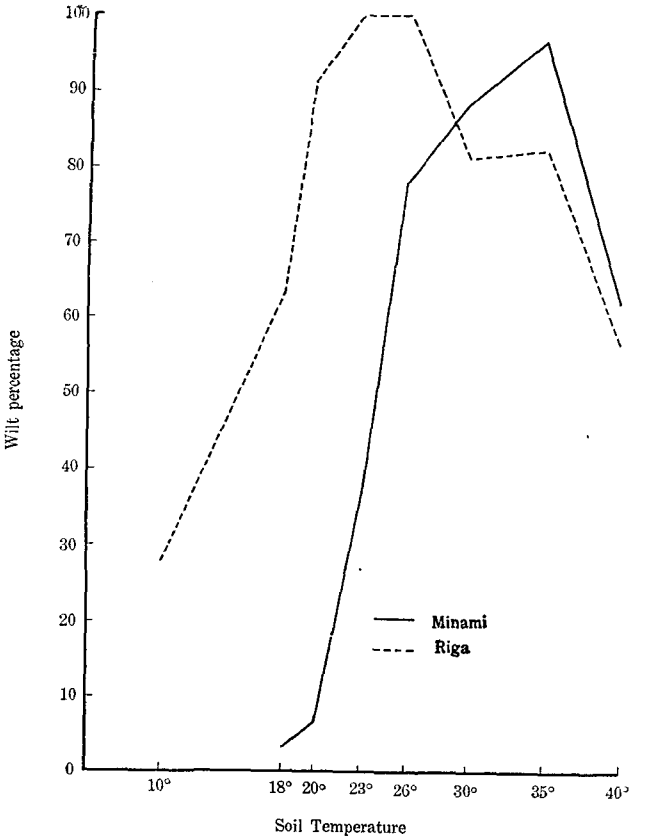
This experiment was carried out at soil temperatures ranged in a series of 10°, 18°, 20°, 23°, 26°, 30°, 35° and 40°C. The soil



Text-fig. IX. Curves showing the wilt percentages of Minami and Riga varieties with respect to different soil temperatures. (Results of Exp. No. 3)

moisture of each pot was controlled to about 45%. Two pots each were used for each plot and 30 grains of sterilized seeds of Minami and Riga varieties were sown side by side in each half of a pot. The seedlings generally emerged at 3 days after sowing, and daily observations on the occurrence of the wilting were continued till the 26th day after the emergence of the seedlings. The percentages of wilted plants were calculated every second day. The data are given in Table 18 and summarized in Text Fig. IX.

As shown in Table 18 and Text Fig. IX, in Minami variety at 10°C. none of the plants showed any symptoms of the wilt disease even at the end of the experiments, while at 18°C. only 3% and at 20°C. only 6.8% of the seedlings wilted. In the cases of the rise



Text-fig. X. Curves showing the wilt percentages at the 26th day after emergence with respect to different soil temperatures.

TABLE 18. Occurrence of the wilt at the different soil temperatures in Experiment No. 3.

Soil temp. (C.)	Variety	Total number of emerged individuals	Daily number of the wilted individuals (A), daily total of the wilted individuals (B) & %-tage of the wilted (C)	Days after emergence											
				4	6	8	10	12	14	16	18	20	22	24	26
10°	Minami	59	A	0	0	0	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0	0	0	0
			C	0	0	0	0	0	0	0	0	0	0	0	0
	Riga	58	A	0	0	0	0	1	1	3	6	1	1	0	3
			B	0	0	0	0	1	2	5	11	12	13	13	16
			C	0	0	0	0	1.72	3.45	8.62	18.97	20.69	22.41	22.41	27.59
18°	Minami	60	A	0	1	1	0	0	0	0	0	0	0	0	0
			B	0	1	2	2	2	2	2	2	2	2	2	2
			C	0	1.67	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
	Riga	60	A	0	0	0	3	8	1	2	9	7	2	0	4
			B	0	0	0	3	11	12	14	23	30	32	34	38
			C	0	0	0	5.00	18.33	20.00	23.33	38.33	50.00	53.33	56.67	63.33
20°	Minami	59	A	0	0	1	2	1	0	0	0	0	0	0	0
			B	0	0	1	3	4	4	4	4	4	4	4	4
			C	0	0	1.69	5.08	6.78	6.78	6.78	6.78	6.78	6.78	6.78	6.78
	Riga	58	A	0	1	9	11	16	5	3	6	2	0	0	0
			B	0	1	10	21	37	42	45	51	53	53	53	53
			C	0	1.72	17.24	36.21	63.79	72.41	77.59	87.93	91.38	91.38	91.38	91.33
23°	Minami	60	A	0	2	3	1	4	1	0	2	4	0	5	0
			B	0	2	5	6	10	11	11	13	17	17	22	22
			C	0	3.33	8.33	10.00	16.67	18.33	18.33	21.67	28.33	28.33	36.67	36.67
	Riga	58	A	4	0	17	18	9	3	1	1	2	3		
			B	4	4	21	39	48	51	52	53	55	58		
			C	6.90	6.90	36.21	67.24	82.76	87.93	89.66	91.38	94.83	100.00		

TABLE 18 (*Continued*).

Soil temp. (C.)	Varitety	Total number of emerged individuals	Daily number of the wilted individuals (A), daily total of the wilted individuals (B) & %-tage of the wilted (C)	Days after emergence											
				4	6	8	10	12	14	16	18	20	22	24	26
26°	Minami	59	A	2	1	13	25	1	1	0	0	1	1	1	0
			B	2	3	16	41	42	43	43	43	44	45	46	46
			C	3.39	5.08	27.12	69.49	71.19	72.88	72.88	72.88	74.58	76.27	77.97	77.97
	Riga	58	A	4	0	25	16	9	2	0	1	1			
			B	4	4	29	45	54	56	56	57	58			
			C	6.90	6.90	50.00	77.59	93.10	96.55	96.55	98.28	100.00			
30°	Minami	60	A	7	8	2	2	4	4	4	12	7	1	1	1
			B	7	15	17	19	23	27	31	43	50	51	52	53
			C	11.67	25.00	28.33	31.67	38 33	45.00	51.67	71.67	83.33	85.00	86.67	88.33
	Riga	58	A	7	7	7	2	2	5	3	9	4	1	0	0
			B	7	14	21	23	25	30	33	42	46	47	47	47
			C	12.07	24.14	36.21	39.66	43.10	51.72	56.90	72.41	79.31	81.03	81.03	81.03
35°	Minami	59	A	19	8	14	4	6	1	3	0	0	0	1	1
			B	19	27	41	45	51	52	55	55	55	55	56	57
			C	32.20	45.76	69.49	76.27	86.44	88.14	93.22	93.22	93.22	93.22	94.92	96.61
	Riga	57	A	17	3	13	8	2	1	3	0	0	0	0	0
			B	17	20	33	41	43	44	47	47	47	47	47	47
			C	29.82	35.09	57.89	71.93	75.44	77.19	82.46	82.46	82.46	82.46	82.46	82.46
40°	Minami	58	A	5	5	12	1	3	3	3	0	2	1	1	0
			B	5	10	22	23	26	29	32	32	34	35	36	36
			C	8.62	17.24	37.93	39.66	44.83	50.00	55.17	55.17	58.62	60.34	62.07	62.07
	Riga	60	A	1	1	11	7	3	4	1	3	0	0	1	2
			B	1	2	13	20	23	27	28	31	31	31	32	34
			C	1.66	3.33	21.66	33.33	38.33	45.00	46.66	51.67	51.67	51.67	53.33	56.67

of the soil temperature to 23°, 26° and 30°C. the wilt percentages increased to 36.7, 78.0 and 88.0% respectively. In the plot of 35°C. the highest wilt percentage, 96.8%, was reached, but at 40°C. it decreased to 62%.

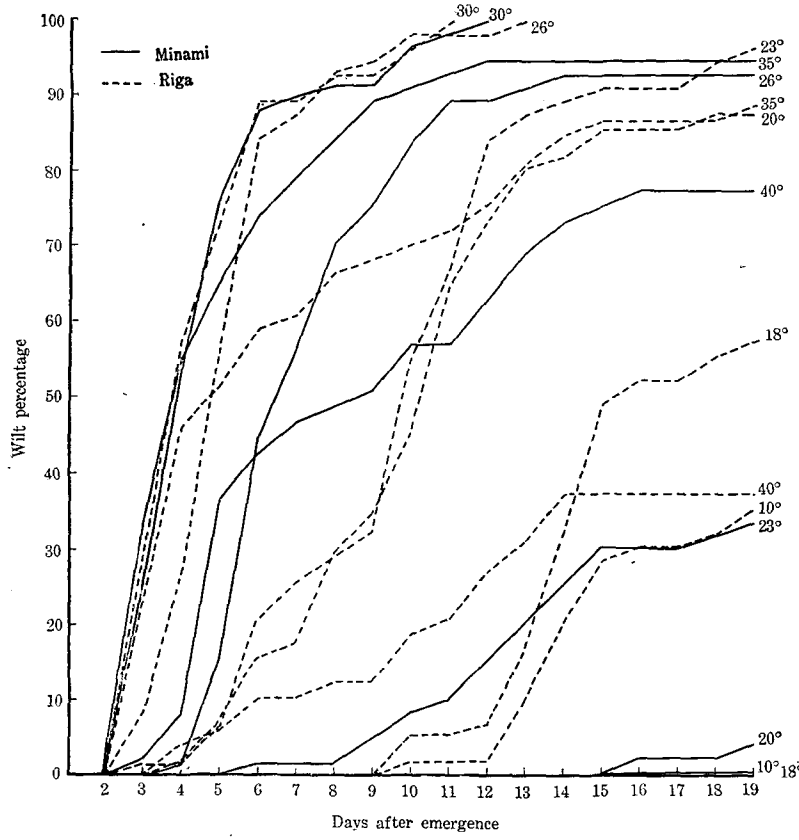
In Riga variety the wilt percentage was as low as 27.5% at 10°C. at the end of the experiment; it increased with the rise of the temperature to 63% at 18°C. and 91% at 20°C., and in the plots of 23°C. and 26°C. the wilt-disease broke out with utmost severity. The entire group of seedlings was annihilated within 22 days at 23°C. and within 20 days at 26°C. In other plots, the percentages of wilted plants at the end of the experiment were 81.0% at 30°C. and 82.5% at 35°C. which decreased promptly to 56.7% at 40°C. It is noticeable that at 40°C. the wilt percentage in Minami variety was higher than that in Riga variety. The curves in Text Fig. X show the variation of the total wilt percentages in Minami and Riga varieties at 26 days after emergence.

Experiment No. 4.

In this experiment the soil temperatures were controlled at 10°, 18°, 20°, 23°, 26°, 30° and 35°C., and the soil moisture of every pot was maintained at about 40%. Two pots each were used for every experimental plot. Thirty grains each of sterilized seeds of both varieties were sown side by side in each half of a pot respectively. The seedlings generally emerged at 4 days after sowing. Daily observations on the occurrence of the wilt were continued from the 2nd to the 19th day after the emergence of the seedlings. The observational data were given in Table 19 and summarized in Text Figs. XI. and XII.

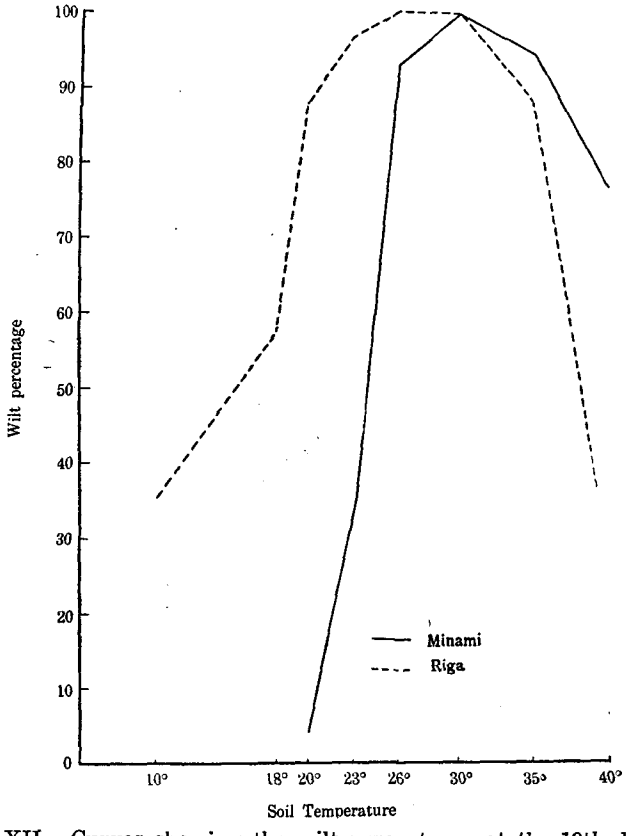
TABLE 19. Occurrence of the wilt at the different soil temperatures in Experiment No. 4.

Soil temp. (C.)	Variety	Total number of emerged individuals	Daily number of the wilted individuals (A), daily total of the wilted individuals (B) & %-tage of the wilted (C)	Days after emergence																
				2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
10°	Minami	59	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Riga	59	A	0	0	0	0	0	0	0	0	1	0	0	5	6	5	1	0	1	2
			B	0	0	0	0	0	0	0	0	1	1	1	6	12	17	18	18	19	21
			C	0	0	0	0	0	0	0	0	1.69	1.69	1.69	10.17	20.34	28.81	30.51	30.51	32.20	35.59
18°	Minami	60	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Riga	59	A	0	0	0	0	0	0	0	0	3	0	1	6	9	10	2	0	2	1
			B	0	0	0	0	0	0	0	0	3	3	4	10	19	29	31	31	33	34
			C	0	0	0	0	0	0	0	0	5.08	5.08	6.78	16.95	32.20	49.15	52.54	52.54	55.93	57.63
20°	Minami	60	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
			B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2
			C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.67	1.67	1.67	3.33
	Riga	57	A	0	0	1	3	5	1	7	3	6	11	5	4	1	2	0	0	1	0
			B	0	0	1	4	9	10	17	20	26	37	42	46	47	49	49	49	50	50
			C	0	0	1.75	7.02	15.79	17.54	29.82	35.09	45.61	64.91	73.68	80.70	82.46	85.96	85.96	85.96	87.72	87.72
23°	Minami	59	A	0	0	0	0	1	0	0	1	3	1	3	3	3	3	0	0	1	1
			B	0	0	0	0	1	1	1	2	5	6	9	12	15	18	18	18	19	20
			C	0	0	0	0	1.69	1.69	1.69	3.39	8.47	10.17	15.25	20.34	25.42	30.51	30.51	30.51	32.20	33.90
	Riga	58	A	0	1	0	3	8	3	2	2	13	7	10	2	1	1	0	0	2	1
			B	0	1	1	4	12	15	17	19	32	39	49	51	52	53	53	53	55	56
			C	0	1.72	1.72	6.90	20.69	25.86	29.31	32.76	55.17	67.24	84.48	87.93	89.66	91.38	91.38	91.38	94.83	96 55
26°	Minami	58	A	0	0	1	8	17	7	8	3	5	3	0	1	1	0	0	0	0	0
			B	0	0	1	9	26	33	41	44	49	52	52	53	54	54	54	54	54	54
			C	0	0	1.72	15.52	44.83	56.90	70.69	75.86	84.48	89.66	89.66	91.38	93.10	93.10	93.10	93.10	93.10	93.10
	Riga	58	A	0	5	11	17	16	2	3	1	2	0	0	1						
			B	0	5	16	33	49	51	54	55	57	57	57	58						
			C	0	8.62	27.59	56.90	84.48	87.93	93.10	94.83	98.28	98.28	98.28	100.00						
30°	Minami	60	A	0	15	18	13	7	1	1	0	3	1	1							
			B	0	15	33	46	53	54	55	55	58	59	60							
			C	0	25.00	55.00	76.67	88.33	90.00	91.67	91.67	96.67	98.33	100.00							
	Riga	57	A	0	16	17	9	9	0	2	0	2	2								
			B	0	16	33	42	51	51	53	53	55	57								
			C	0	28.07	57.89	73.68	89.47	89.47	92.98	92.98	96.49	100.00								
35°	Minami	58	A	0	19	13	6	5	3	3	3	1	1	1	0	0	0	0	0	0	0
			B	0	19	32	38	43	46	49	52	53	54	55	55	55	55	55	55	55	55
			C	0	32.76	55.17	65.52	74.14	79.31	84.48	89.96	91.38	93.10	94.83	94.83	94.83	94.83	94.83	94.83	94.83	94.83
	Riga	54	A	0	13	12	3	4	1	3	1	1	1	2	3	2	1	0	0	0	1
			B	0	13	25	28	32	33	36	37	38	39	41	44	46	47	47	47	47	48
			C	0	24.07	46.30	51.85	59.26	61.11	66.67	68.52	70.37	72.22	75.93	81.48	85.19	87.04	87.04	87.04	87.04	88.89
40°	Minami	49	A	0	1	3	14	3	2	1	1	3	0	3	3	2	1	1	0	0	0
			B	0	1	4	18	21	23	24	25	28	28	31	34	36	37	38	38	38	38
			C	0	2.04	8.16	36.73	42.86	46.94	48.98	51.02	57.14	57.14	63.27	69.39	73.47	75.51	77.55	77.55	77.55	77.55
	Riga	48	A	0	0	2	1	2	0	1	0	3	1	3	2	3	0	0	0	0	0
			B	0	0	2	3	5	5	6	6	9	10	13	15	18	18	18	18	18	18
			C	0	0	4.17	6.25	10.42	10.42	12.50	12.50	18.75	20.83	27.08	31.25	37.50	37.50	37.50	37.50	37.50	37.50



Text-fig. XI. Curves showing the wilt percentages of Minami and Riga varieties with respect to different soil temperatures.

As shown in Table 19 and in Text Figs. XI and XII, in Minami variety none of the seedlings in the plots of 10° and 18°C. showed any symptoms of wilt disease, and in the plot of 20°C. the wilt percentage was only 4%. Above 23°C. the wilt percentages increased rapidly coordinately with the rise of soil temperatures. In the plot of 30°C. the wilt disease occurred most severely 100% of the seedlings being killed within 12 days after emergence, and in the plots of 35° and 40°C. the wilt percentages were 94.8% and 77.5% respectively. In Riga variety 35.59% of the seedlings wilted even at 10°C. and in plots of 18°, 20° and 23°C., the wilt percentages were calculated as 57.5, 87.7 and 96.5% respectively. The greatest wilt occurrence was observed in the plots of 26° and 30°C. in which all the seedlings were annihilated within 11 and 13 days after their emergence. Above 35°C. the occurrence of the wilt decreased more



Text-fig. XII. Curves showing the wilt percentages at the 19th day after emergence with respect to different soil temperatures.

conspicuously than in the cases of Minami variety in accord with the rise of the soil temperature, and the wilt percentages were 88.89% at 35°C. and 37.50% at 40°C.

Experiment No. 5.

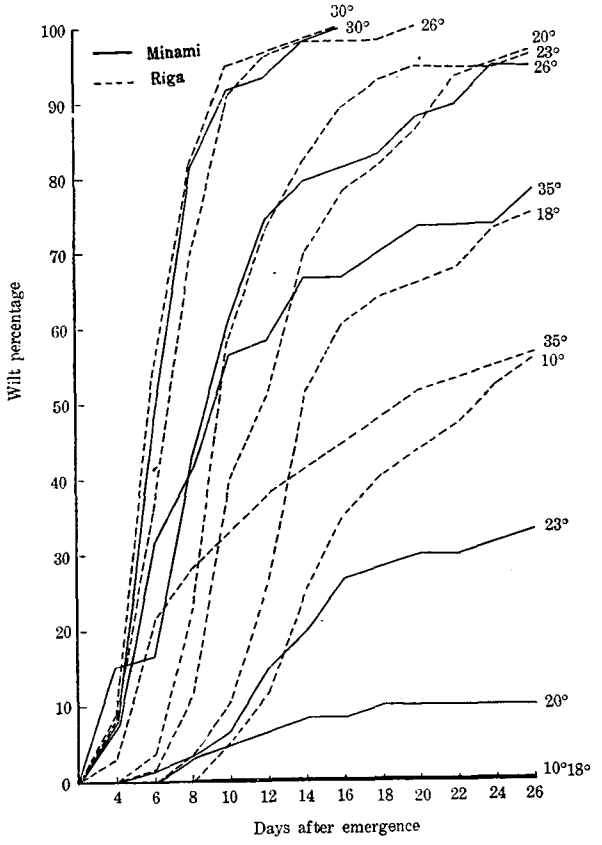
The soil temperatures in this experiment were controlled at 10°, 18°, 20°, 23°, 26°, 30 and 35°C., and the soil moisture of every pot was regulated at about 41%. Thirty sterilized seeds each of Riga and Minami varieties were sown side by side in each half of a pot respectively and two pots each were used for every experimental plot. The seedlings emerged 4 days after sowing, and daily observations on the occurrence of the wilt disease were continued from the 4th to the 26th day after the emergence of the seedlings. The results of the observations are shown in Table 20 and summarized in Text Figs. XIII and XIV.

TABLE 20. Occurrence of the wilt at the different soil temperatures in Experiment No. 1.

Soil temp. (C.)	Variety	Total number of emerged individuals	Daily number of the wilted individuals (A), daily total of the wilted individuals (B) & %-tage of the wilted (C)	Days after emergence											
				4	6	8	10	12	14	16	18	20	22	24	26
10°	Minami	60	A	0	0	0	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0	0	0	0
			C	0	0	0	0	0	0	0	0	0	0	0	0
	Riga	59	A	0	0	0	3	4	8	6	3	2	2	3	2
			B	0	0	0	3	7	15	21	24	26	28	31	33
			C	0	0	0	5.08	11.86	25.42	35.59	40.68	44.07	47.46	52.54	55.93
18°	Minami	60	A	0	0	0	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0	0	0	0
			C	0	0	0	0	0	0	0	0	0	0	0	0
	Riga	56	A	0	0	2	4	9	14	5	2	1	1	3	1
			B	0	0	2	6	15	29	34	36	37	38	41	42
			C	0	0	3.57	10.71	26.79	51 79	60.71	64.29	66.07	67.86	73.21	75.00
20°	Minami	60	A	0	0	2	1	1	1	0	1	0	0	0	0
			B	0	0	2	3	4	5	5	6	6	6	6	6
			C	0	0	3.33	5.00	6.67	8.33	8.33	10.00	10.00	10.00	10.00	10.00
	Riga	60	A	0	1	6	17	7	11	5	2	3	4	1	1
			B	0	1	7	24	31	42	47	49	52	56	57	58
			C	0	1.67	11.67	40.00	51.67	70.00	78.33	81.67	86.67	93.33	95.00	96.67
23°	Minami	60	A	0	1	1	2	5	3	4	1	1	0	1	1
			B	0	1	2	4	9	12	16	17	18	18	19	20
			C	0	1.67	3.33	6.67	15.00	20.00	26.67	28.33	30.00	30.00	31.67	33.33
	Riga	56	A	0	2	11	20	8	5	4	2	1	0	0	1
			B	0	2	13	33	41	46	50	52	53	53	53	54
			C	0	3.57	23.21	58.93	73.21	82.14	89.29	92.86	94.64	94.64	94.64	96.43

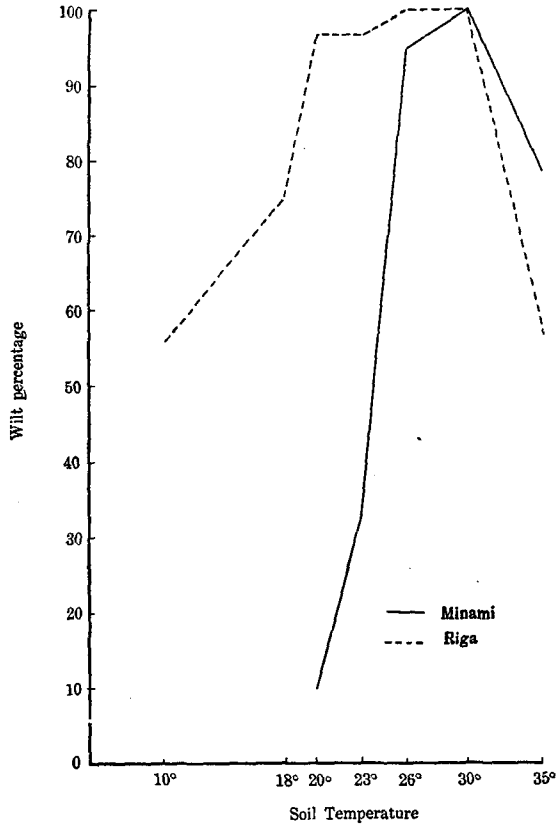
TABLE 20. (*Continued*).

Soil temp. (C.)	Variety	Total number of emerged individuals	Daily number of the wilted individuals (A), daily total of the wilted individuals (B) & %-tage of the wilted (C)	Days after emergence											
				4	6	8	10	12	14	16	18	20	22	24	26
26°	Minami	59	A	9	1	15	11	8	3	1	1	3	1	3	0
			B	9	10	25	36	44	47	48	49	52	53	56	56
			C	15.25	16.95	42.37	61.02	74.58	79.66	81.36	83.05	88.14	89.83	94.92	94.92
	Riga	56	A	5	15	19	12	3	1	0	0	1			
			B	5	20	39	51	54	55	55	55	56			
			C	8.93	35.71	69.64	91.07	96.43	98.21	98.21	98.21	100.00			
30°	Minami	60	A	5	24	20	6	1	3	1					
			B	5	29	49	55	56	59	60					
			C	8.33	48.33	81.67	91.67	93.33	98.33	100.00					
	Riga	60	A	5	27	17	8	1	1	1					
			B	5	32	49	57	58	59	60					
			C	8.33	53.33	81.67	95.00	96.67	98.33	100.00					
35°	Minami	60	A	5	14	6	9	1	5	0	2	2	0	0	3
			B	5	19	25	34	35	40	40	42	44	44	44	47
			C	8.33	31.67	41.67	56.67	58.33	66.67	66.67	70.00	73.33	73.33	73.33	78.33
	Riga	60	A	2	11	4	3	3	2	2	2	2	1	1	1
			B	2	13	17	20	23	25	27	29	31	32	33	34
			C	3.33	21.67	28.33	33.33	38.33	41.67	45.00	48.33	51.67	53.33	55.00	56.67



Text-fig. XIII. Curves showing the wilt percentages of Minami and Riga varieties with respect to different soil temperatures.

From the above table and Text Fig. XIV it is evident that the results of the present experiment are quite similar with those of exp. No. 4. Minami variety showed none of the wilt symptoms in the plots of 10°C. and 18°C., and only 10% of the plants wilted in the plot of 20°C. At 23°C. and 26°C. ca. 33% and ca. 95% of the plants were killed, and at 30°C. all the plants were annihilated within 16 days after the emergence of the seedlings. In the plot of 35°C. the wilt percentage was ca. 78% which was far higher than that (56.6%) in the case of Riga variety at the same temperature. While in Riga variety ca. 56% of the seedlings were wilted at 10°C., in the plots of 18°, 20° and 23°C., the wilt percentages were calculated as ca. 75.0, ca. 9.0 and ca. 97.0% respectively.



Text-fig. XIV. Curves showing the wilt percentages at the 26th day after emergence with respect to different soil temperatures.

Experiment No. 6.

In this experiment the soil temperatures were controlled at 10°, 16°, 20°, 23°, 26°, 30°, 33°, 38°, and 45°C. In check plot, the soil temperature was uncontrolled and it varied according to the variation of room temperature (15°–27°C.) in the greenhouse.

Two pots each were used for each plot and the soil moisture of each pot was maintained at about 42%. Thirty sterilized seeds each of Riga and Minami varieties were sown side by side in each half of a pot respectively. The seedlings emerged 3 or 4 days after sowing, and daily observations on the occurrence of the wilt

TABLE 21. Occurrence of the wilt in Minami variety at the different soil temperatures in Experiment No. 6.

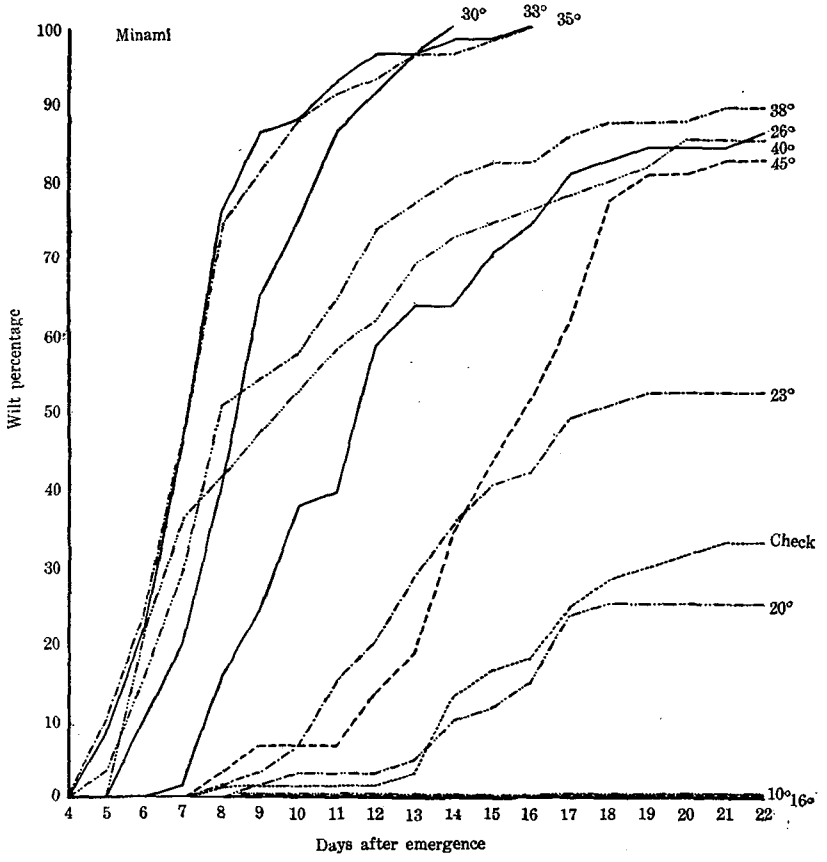
Soil temp. (C.)	Total number of emerged individuals	Daily number of the wilted individuals (A), daily total of the wilted individuals (B) & %-tage of the wilted (C)	Days after emergence																	
			4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
10°	60	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16°	60	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20°	59	A	0	0	0	0	0	1	1	0	0	1	3	1	2	5	1	0	0	0	0
		B	0	0	0	0	0	1	2	2	2	3	6	7	9	14	15	15	15	15	15
		C	0	0	0	0	0	1.69	3.39	3.39	3.39	5.08	10.17	11.86	15.25	23.73	25.42	25.42	25.42	25.42	25.42
23°	59	A	0	0	0	0	1	1	2	5	3	5	4	3	1	4	1	1	0	0	0
		B	0	0	0	0	1	2	4	9	12	17	21	24	25	29	30	31	31	31	31
		C	0	0	0	0	1.69	3.39	6.78	15.25	20.34	28.81	35.59	40.68	42.37	49.15	50.85	52.54	52.54	52.54	52.54
26°	58	A	0	0	0	1	8	5	8	1	11	3	0	4	2	4	1	1	0	0	1
		B	0	0	0	1	9	14	22	23	34	37	37	41	43	47	48	49	49	49	50
		C	0	0	0	1.72	15.52	24.14	37.93	39.66	58.62	63.79	63.79	70.69	74.14	81.03	82.76	84.48	84.48	84.48	86.21
30°	60	A	0	0	6	6	12	15	6	4	6	3	2								
		B	0	0	6	12	24	39	45	49	55	58	60								
		C	0	0	10.00	20.00	40.00	65.00	75.00	81.67	91.67	96.67	100.00								
33°	59	A	0	5	8	14	18	6	1	3	2	0	1	0	1						
		B	0	5	13	27	45	51	52	55	57	57	58	58	59						
		C	0	8.48	22.03	45.76	76.27	86.44	88.14	93.22	96.61	96.61	98.31	98.31	100.00						
35°	59	A	0	6	8	13	17	4	4	2	1	2	0	1	1						
		B	0	6	14	27	44	48	52	54	55	57	57	58	59						
		C	0	10.17	23.73	45.76	74.58	81.36	88.14	91.53	93.22	96.61	96.61	98.31	100.00						
38°	57	A	0	2	7	8	12	2	2	4	5	2	2	1	0	2	1	0	0	1	0
		B	0	2	9	17	29	31	33	37	42	44	46	47	47	49	50	50	50	51	51
		C	0	3.51	15.79	29.82	50.88	54.39	57.89	64.91	73.68	77.19	80.70	82.46	82.46	85.96	87.72	87.72	87.72	89.47	89.47
40°	55	A	0	0	12	8	3	3	3	3	2	44	2	1	1	1	1	1	2	0	0
		B	0	0	12	20	23	26	29	32	34	38	40	41	42	43	44	45	47	47	47
		C	0	0	21.82	36.36	41.82	47.27	52.73	58.18	61.82	69.09	72.73	74.55	76.36	78.18	80.00	81.82	85.45	85.45	85.45
45°	58	A	0	0	0	0	2	2	0	0	4	3	9	4	6	6	9	2	0	1	0
		B	0	0	0	0	2	4	4	4	8	11	20	24	30	36	45	47	47	48	48
		C	0	0	0	0	3.45	6.90	6.90	6.90	13.79	18.97	34.48	41.38	51.72	62.07	77.59	81.03	81.03	82.76	82.76
Check plot	60	A	0	0	0	0	1	0	0	0	0	1	6	2	1	4	2	1	1	1	0
		B	0	0	0	0	1	1	1	1	1	2	8	10	11	15	17	18	19	20	20
		C	0	0	0	0	1.67	1.67	1.67	1.67	1.67	3.33	13.33	16.67	18.33	25.00	28.33	30.00	31.67	33.33	33.33

TABLE 22. Occurrence of the wilt in Riga variety at the different soil temperatures in Experiment No. 6.

Soil temp. (C.)	Total number of emerged individuals	Daily number of the wilted individuals (A), total number of the wilted individual (B) & %-tage of the wilted (C)	Days after emergence																	
			4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
10°	59	A	0	0	0	0	0	1	0	1	0	2	0	5	0	2	4	3	2	0	1
		B	0	0	0	0	0	1	1	2	2	4	4	9	9	11	15	18	20	20	21
		C	0	0	0	0	0	1.69	1.69	3.39	3 39	6.78	6.78	15.25	15.25	18.64	25.42	30.51	33.90	33.90	35.59
16°	60	A	0	0	0	0	0	2	0	5	5	2	4	5	6	6	2	1	0	0	2
		B	0	0	0	0	0	2	2	7	12	14	18	23	29	35	37	38	38	38	40
		C	0	0	0	0	0	3.33	3.33	11.67	20.00	23.33	30.00	38.33	48.33	58.33	61.67	63.33	63.33	63.33	66.67
20°	59	A	0	0	0	0	6	11	12	6	6	9	3	0	0	1	0	0	0	0	0
		B	0	0	0	0	6	17	29	35	41	50	53	53	53	54	54	54	54	54	54
		C	0	0	0	0	10.17	28.81	49.15	59.32	69 49	84.75	89.83	89.83	89.83	91.53	91.53	91.53	91.53	91.53	91 53
23°	60	A	0	0	0	1	9	13	13	11	5	1	2	1	0	1	0	0	0	0	2
		B	0	0	0	1	10	23	36	47	52	53	55	56	56	57	57	57	57	57	59
		C	0	0	0	1.67	6.67	38.33	60.00	78.33	86.67	88.33	91.67	93.33	93.33	95.00	95.00	95.00	95.00	95.00	98.33
26°	60	A	0	0	1	6	23	14	8	4	1	1	1	1							
		B	0	0	1	7	30	44	52	56	57	58	59	60							
		C	0	0	1.67	11.67	50.00	73.33	86.67	93.33	95.00	96.67	98.33	100.00							
30°	58	A	0	1	7	10	21	10	3	2	2	2									
		B	0	1	8	18	39	49	52	54	56	58									
		C	0	1.72	13.79	31.03	67.24	84.48	89.66	93.10	96.55	100.00									
33°	59	A	0	2	9	18	16	4	2	2	2	0	1	1	1	0	1				
		B	0	2	11	29	45	49	51	53	55	55	56	57	58	58	59				
		C	0	3.39	18.64	49.15	76.27	83.05	86.44	89.83	93.22	93.22	94.92	96.61	98.31	98.31	100.00				
35°	60	A	0	3	6	10	10	5	5	7	7	2	3	0	0	0	0	0	0	0	0
		B	0	3	9	19	29	34	39	46	53	55	58	58	58	58	58	58	58	58	58
		C	0	5.00	15.00	31.67	48.33	56.67	65.00	76.67	88.33	91.67	96.67	96.67	96.67	96.67	96.67	96.67	96.67	96.67	96.67
38°	57	A	0	1	7	8	12	5	3	1	1	3	2	3	1	2	0	1	0	1	1
		B	0	1	8	16	28	33	36	37	38	41	43	46	47	49	49	50	50	51	52
		C	0	1.75	14.08	28.07	49.12	57.89	63.16	64.91	66.67	71.93	75.44	80.70	82.46	85.96	85.96	87.72	87.72	89.47	91.23
40°	57	A	0	1	5	6	2	2	1	1	5	3	5	3	1	4	3	3	0	0	1
		B	0	1	6	12	14	16	17	18	23	26	31	34	35	39	42	45	45	45	46
		C	0	1.75	10.53	21.05	24.56	28.07	29.82	31.58	40.35	45.61	54.39	59.65	61.40	68.42	73.68	78.95	78.95	78.95	80.70
45°	58	A	0	0	0	0	3	1	0	0	1	2	7	5	1	7	2	2	0	3	1
		B	0	0	0	0	3	4	4	4	5	7	14	19	20	27	29	31	31	34	35
		C	0	0	0	0	5.17	6.90	6.90	6.90	8.62	12.07	24.14	32.76	34.48	46.55	50.00	53.45	53.45	58.62	60.34
Check plot	60	A	0	0	0	0	8	9	3	2	7	10	8	4	2	1	1	1	0	0	0
		B	0	0	0	0	8	17	20	22	29	39	47	51	53	54	55	56	56	56	56
		C	0	0	0	0	13.33	28.33	33.33	36.67	48.33	65.00	78.33	85.00	88.33	90.00	91.67	93.33	93.33	93.33	93.33

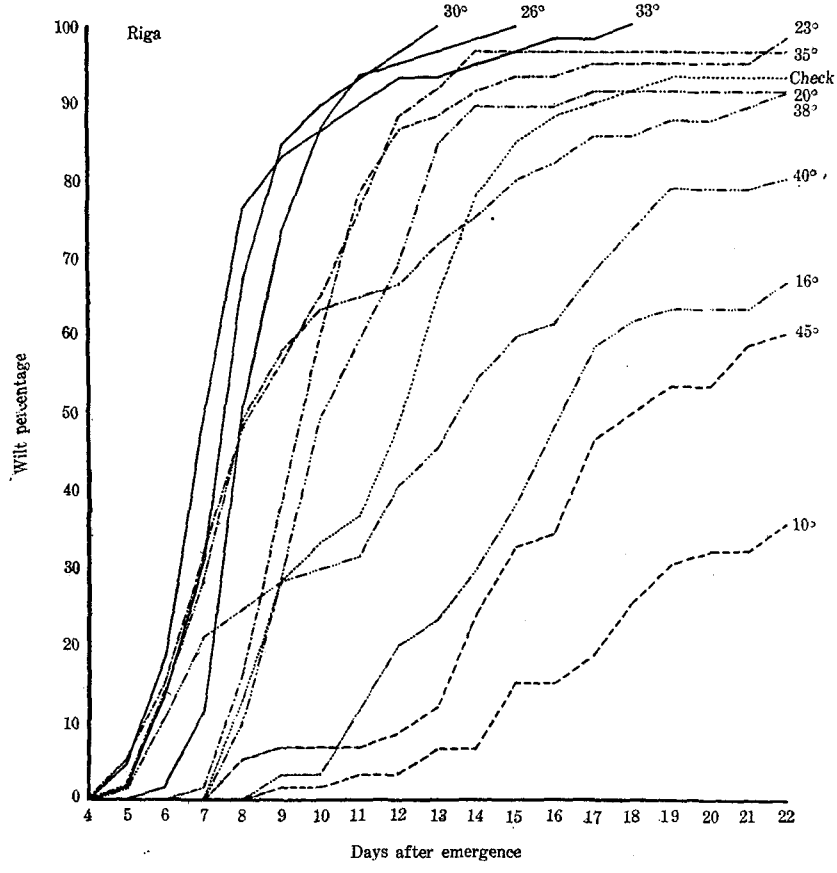
disease were continued from the 4th to the 22nd day after emergence of the seedlings. Observational data are shown in Tables 21 and 22, and graphed in Text Figs. XV, XVI, and XVII.

As shown in these tables and text figures, the wilt percentages in relation to the rise of soil temperature increased more rapidly in Riga variety than in Minami variety until the maximum was reached at 30°C. All the plants of Riga variety were destroyed by the wilt within 15 days at 26°C, within only 13 days at 30°C. and within 18 days at 33°C. after the emergence of the seedlings. In Minami variety, none of the plants showed any symptoms of the wilt disease in the plots of 10° and 16°C., and at 20°, 23° and



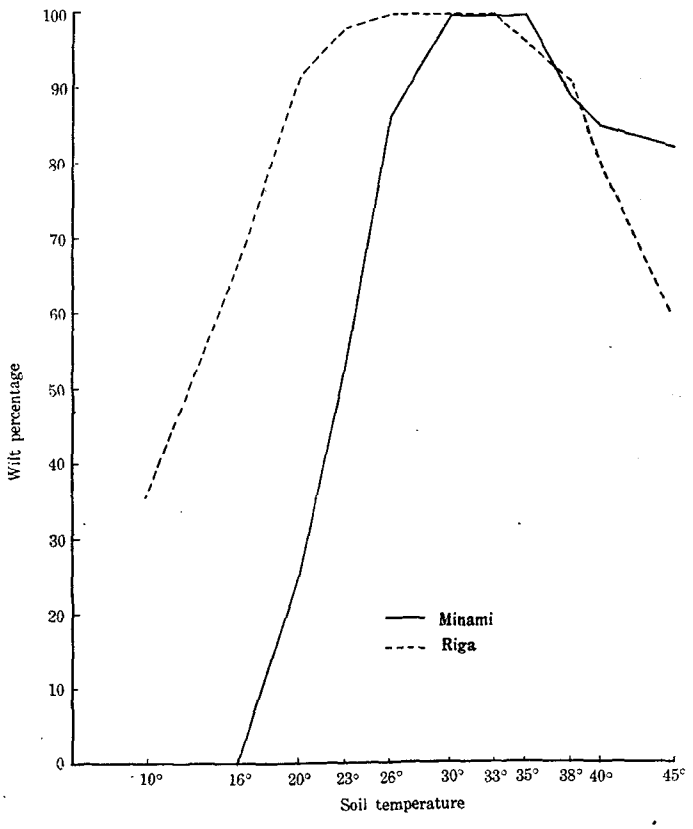
Text-fig. XV. Curves showing the wilt percentages of Minami variety with respect to different soil temperatures.

26°C. the wilted plants were ca. 25%, ca. 50% and ca. 86% respectively, in contrast with the cases in Riga variety as ca. 35.6% at 10°C., 66.7% at 16°C., ca. 91.5% at 20°C., ca. 98% at 23°C. and just 100% at 26°C. At 30°, 33°, and 35°C., however, the whole number of seedlings of Minami variety was annihilated. Especially



Text-fig. XVI. Curves showing the wilt percentages of Riga variety with respect to different soil temperatures.

at 30°C. the disease ravaged the plants most severely and all of them were killed rapidly within 14 days after emergence. At 33°C. and 25°C. the annihilation of the plants took place within 16 days. Above the optimum soil temperature for the occurrence of the wilt disease, 30°C., the wilt percentage decreased more rapidly in Riga



Text-fig. XVII. Curves showing th wilt percentages at the 32nd day after emergence with respect to different soil temperatures.

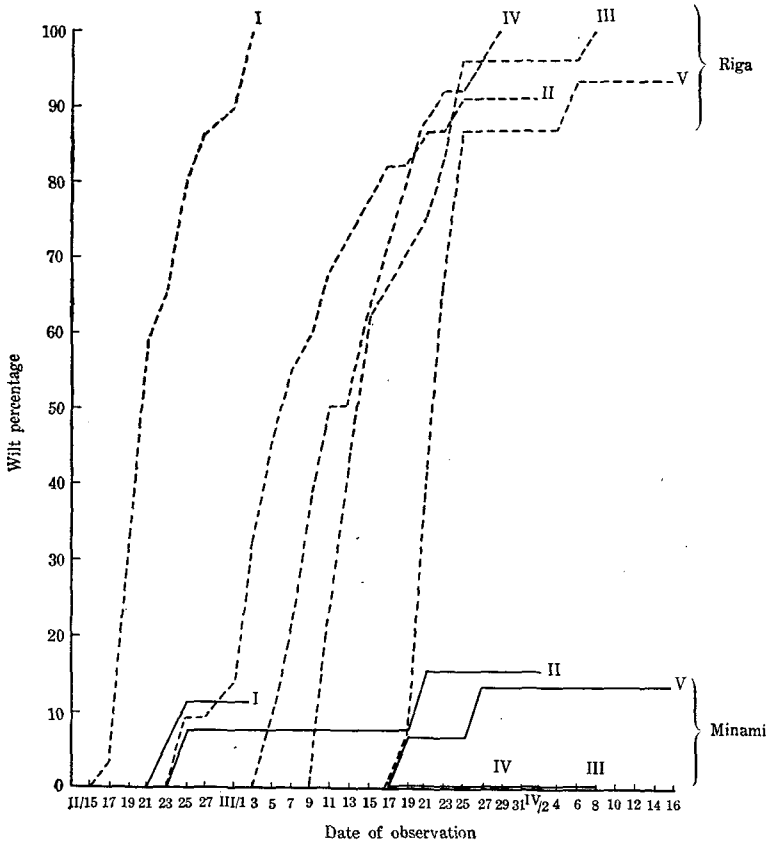
variety as 96.7, 91.2, 80.7 and 60.3% at 35°, 38°, 40°, and 45°C. respectively than in Minami variety as 100.0, 89.5, 85.5 and 82.8% at 35°, 38°, 40° and 45°C., respectively.

In the check plot a distinct difference in the wilt percentage was observed between these two varieties; in Minami variety it was only 33.3% while in Riga it was 93.3% at the end of the experiment.

Experiment No. 7.

The wilt promoting influence of high soil temperature has been recognized in the foregoing experiments. The present experiment was carried out in order to examine the effects of low temperature

treatment on resistance and susceptibility to the wilt of the seedlings of Minami and Riga varieties. From 25 to 30 sterilized seeds of Minami and Riga varieties were sown side by side in the respective halves of pots containing sick soil. Every pot was exposed to low atmospheric temperature ranging from 2°C. to 7°C. Seedlings emerged between 23 to 25 days after seed-sowing, a great part of them emerging on the 24th day. Each pair of pots was removed into



Text-fig. XVIII. Curves showing the wilt percentages in Exp. No. 7.

a greenhouse (15°–27°C.) and the development of the seedlings and the occurrence of wilt were observed. The data obtained are given in Tables 23 and 24, and summarized in Text Fig. XVIII.

TABLE 23. Occurrence of the wilt in Minami and Riga varieties raised in cool place for different periods.[1]
(Experiment No. 7.)

Plot	Date of removal from cool place into greenhouse	Period of low temp. treatment (days)[2]	Variety	Total number of emerged seedlings	Daily number of the wilted individuals (A), daily total of the wilted individuals (B) & %-tage of the wilted (C)	Date of observation																																	
						Feb. 17	19	21	23	25	27	Mar. 1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	Apr. 2	4	6	8	10	12	14	16						
						Days elapsed after emergence																																				
						17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75						
I	Feb. 7	29	Minami	18	A	0	0	0	1	1	0	0	0																													
					B	0	0	0	1	2	2	2	2																													
					C	0	0	0	5.56	11.11	11 11	11.11	11.11																													
			Riga	29	A	1	8	8	2	4	2	1	3																													
					B	1	9	17	19	23	25	26	29																													
					C	3.45	31.03	58.62	65.52	79.31	86.21	89.66	100.00																													
II	Feb. 14	36	Minami	26	A				0	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0											
					B				0	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4											
					C				0	7.69	7.69	7.69	7.69	7.69	7.69	7.69	7.68	7.69	7.69	7.69	7.69	15.38	15.38	15.38	15.38	15.38	15.38	15.38	15.38											
			Riga	22	A				0	2	0	1	4	3	2	1	2	1	1	1	0	1	0	1	0	0	0	0	2											
					B				0	2	2	3	7	10	12	13	15	16	17	18	18	19	19	20	20	20	20	20	22											
					C				0	9.09	9.09	13.64	31.82	45.45	54.55	59.09	68.18	72.73	77.27	81.82	81.82	86.36	86.36	90.91	90.91	90.91	90.91	90.91	100.00											
III	Feb. 21	43	Minami	29	A								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
					B								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
					C								0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
			Riga	24	A								0	2	3	4	3	0	3	2	2	2	1	0	1	0	0	0	0	0	1									
					B								0	2	5	9	12	12	15	17	19	21	22	22	23	23	23	23	23	23	24									
					C								0	8.33	20.83	37.50	50.00	50.00	62.50	70.83	79.17	87.50	91.67	91.67	95.83	95.83	95.83	95.83	95.83	95.83	100.00									
IV	Feb. 28	50	Minami	30	A											0	0	0	0	0	0	0	0	0	0	0															
					B											0	0	0	0	0	0	0	0	0	0	0															
					C											0	0	0	0	0	0	0	0	0	0	0															
			Riga	24	A											0	5	5	5	1	1	1	2	3	0	1															
					B											0	5	10	15	16	17	18	20	23	23	24															
					C											0	20.83	41.67	62.50	66.67	70.83	75.00	83.33	95.83	95.83	100.00															
V	Mar. 7	57	Minami	30	A															0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0					
					B															0	2	2	2	2	4	4	4	4	4	4	4	4	4	4	4					
					C															0	6.67	6.67	6.67	6.67	13.33	13.33	13.33	13.33	13.33	13.33	13.33	13.33	13.33	13.35	13.33					
			Riga	30	A															0	2	12	8	6	0	0	0	0	0	2	0	0	0	0	0					
					B															0	2	12	20	26	26	26	26	26	26	28	28	28	28	28	28					
					C															0	6.67	40.00	66.67	86.67	86.67	86.67	86.67	86.67	86.67	93.33	93.33	93.33	93.33	93.33	93.33					

(1) sown on Jan. 10 and emerged on Feb. 1. (2) days elapsed from sowing (Jan. 10) to removing.

TABLE 24. Showing the increases of hypocotyl length of flax seedlings which have been raised at low temperature of 2°-7°C. for varying lengths of time after removal to greenhouse.(1)

Plot	Variety	Date of observation																					
		Feb. 17	19	21	23	25	27	Mar. 1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
I	Minami	2.0	3.5	4.5	5.9	6.2	6.7	7.2	7.5														
	Riga	2 0	3.2	4.0	4.7	4.9	5.3	5.7	6.0														
II	Minami				1.9	2.0	3.2	4.0	5.2	6.1	6.9	7.5	9.0	9.4									
	Riga				2.0	2.5	3.4	4.1	5.1	5.6	6.3	6.6	6.8	6.8									
III	Minami									2.9	3.6	4.4	6.0	6.8	7.4	8.3	9.3						
	Riga									3.3	4.1	4.8	5.8	6.5	7.4	7.9	8.0						
IV	Minami												3.0	3.2	4.6	5.9	6.7	7.9	8.6	8.8	9.4		
	Riga												3.0	3.2	4.4	4.7	5.0	5.0	5.0	5.0	5.0		
V	Minami															3.0	3.6	4.9	5.3	5.7	6.6	7.0	7.7
	Riga															3.5	4.0	4.6	5.0	5.4	5.6	5.6	5.6

(1) mean value of 10 individuals in cm.

In the first experiment the seedlings were raised in a cool place of 2°–7°C. during 29 days after sowing, or 7 days after emergence of seedlings before removal into a greenhouse in which the temperature ranged from 15° to 27°C. The hypocotyls of seedlings developed 2.0 cm. in length (cf. Table 24) and none of the seedlings showed any symptoms of the wilt disease at that time. In Minami variety the wilt first appeared after 17 days from the removal (i.e. after 23 days from emergence), and after 25 days from the removal (at the end of the experiment), only 11% of wilted seedlings appeared; in Riga variety the first occurrence of wilt was observed after 11 days from the removal and all the seedlings were entirely annihilated in the same period.

In the second experiment, seedlings were kept in a cool place (2°–7°C.) for 14 days after emergence and then they were removed into a greenhouse (15°–27°C.) at which time no wilting symptom appeared. At that time the average length of hypocotyls measured 1.9 cm. in Minami variety and 2.0 cm. in Riga variety (cf. Table 24). Twelve days later (i.e. 25 days after emegence) wilting first occurred in both varieties, and after 50 days from the removal the wilt percentage in Minami variety was only 15.38%, while all the plants of Riga variety were killed in the same period.

In the third experiment, the seedings were kept in a cool place (2°–7°C.) for 21 days after emergence and then they were removed into a greenhouse (15°–27°C.). At the time of the removal, no symptom of the wilt disease was recognized and the average length of the hypocotyls measured 2.9 cm. in Minami variety and 3.3 cm. in Riga variety (cf. Table 24). After the removal to the greenhouse, in Minami variety all the plants remained healthy until the 38th day; while in Riga variety 8.3% of wilting was observed after 13 days from the removal (i.e. after 33 days from emergence) and all plants were killed by the end of the experiment.

In the fourth experiment, seedlings were kept in low temperature (2°–7°C.) for 28 days after emergence and they were then removed into a greenhouse (15°–27°C.). When they were removed, the average length of hypocotyls was 3.0 cm. in both varieties and none of the plants showed any symptom of the wilt disease. In the greenhouse, all plants of Minami variety remained healthy during the experiment; however, in Riga variety, the wilt disease occurred promptly and 20.8% of the plants were killed after 11 days from

the removal (i.e. 39 days after emergence), and all the plants were annihilated after 29 days from the removal (i.e. 57 days after emergence).

In the fifth experiment, the seedlings were kept at the cool temperature of 2°–7°C. for 35 days after emergence, and then they were removed into a greenhouse (15°–27°C.). When they were removed the average hypocotyl length of the seedlings was 3.0 cm is Minami variety and 3.5 cm. in Riga variety. The seedlings were all sound and none of them showed any sign of the wilt disease. After 13 days from the removal (i.e. 47 days after emergence) each variety showed 6.67% of wilting. At the end of the experiment (41 days after the removal), only 13.3% of the plants in Minami variety, but 93% in Riga variety, were killed.

From Tables 23, 24 and Text Fig. XVIII, it is clear that both varieties exhibited in every experiment their resistant or susceptible character to the wilt. Raising the seedlings at low temperature in their early stage did not exert any peculiar effect upon their predisposition in respect to the wilt resistance.

In connection with the previous experiment the writer observed the variation of soil temperature at the depth of 5–6 cm. from the surface in flax field from sowing to ripening in 1935. The following table shows the soil temperatures from 1 May to 24 July, the flax season in Hokkaido.

In nature the soil temperature of a field varied widely within a day. The maximum temperature was reached at noon to 2 p.m. in general, and it became lower and lower until its minimum was reached before the next morning.

After sun rise the soil temperature ascended gradually. The maximum soil temperatures in the field at the seedling period of flax in Hokkaido were generally lower than 20°C., at which the wilt disease breaks out on the susceptible flax varieties, but not on resistant Minami variety, as is clear from the results of the experiments carried out at artificially regulated soil temperatures.

(3) General conclusion to the studies of the influence of soil temperature on the occurrence of the wilt disease

The writer proposes to consider the results obtained in the comparative experiments of the influence of soil temperature on

TABLE 25. Observation on soil temperature in flax field. 1935.

Date	Average temp. of every 5 days	Maximum in every 5 days	Minimum in every 5 days
V/1- 5	11.78	13.50	6.5
6-10	12.31	15.26	10.37
11-15	13.48	17.50	12.50
16-20	14.16	17.85	10.00
21-25	14.66	18.20	11.30
26-30	17.06	20.30	12.80
31-VI/4	19.00	20.46	13.74
5- 9	18.91	19.78	13.40
10-14	20.97	25.22	17.10
15-19	20.49	25.02	18.02
20-24	20.85	23.10	18.02
25-29	22.68	25.84	17.04
30-VII/4	22.80	24.18	18.10
5- 9	20.24	24.07	16.30
10-14	19.18	23.01	16.64
15-19	24.02	24.32	19.70
20-24	23.40	24.25	20.74

the occurrence of the wilt disease with the resistant Minami variety and susceptible Riga variety. In the experiments described just above the soil temperature and soil moisture were artificially controlled, and the other environmental factors were also kept as nearly uniform as possible. For the infection source sick soil was taken from the field successively cropped in flax, which had been proved to be highly infected with the wilt disease.

All the experiments, No. 1 – No. 6, generally showed a conspicuous difference between Minami and Riga varieties with regard to the resistance and susceptibility to the wilt disease. In Exps. Nos. 1 and 2, the seedlings of Minami variety were first annihilated by the wilt disease at the soil temperature of 30°C. within 20 days, but the seedlings of Riga variety were annihilated at 25°C. within 20 days and at 30°C. within 15 days. The increase of the wilt percentage caused by the rise of soil temperature was far more rapid in Riga variety than in Minami variety until its maximum

was reached at 30°C,. while above 30°C. the decrease of the wilt percentage was more conspicuous in Riga variety than in Minami variety and the latter was attacked more severely than the former.

Experiments Nos. 3, 4, 5 and 6 were carried out at finer gradations of the soil temperature than in previous ones. The results of these experiments as a whole demonstrated more accurately the tendencies of resistant or susceptible characters of the two varieties to the wilt disease shown in the first and second experiments. However, in Exp. No. 3 the occurrence of the wilt seemed generally to be retarded to some extent. That is, in Riga variety all the seedlings were annihilated by the wilt disease at 23°and 26°C. within 22 and 20 days after emergence, while the seedlings of Minami variety were never annihilated at any soil temperature examined and at 35°C. they showed 96.6% wilting, the maximum, at the end of the experiment (i.e. 26 days after emergence). In this experiment the soil moisture was about 45%, higher than in the others (about 40–42%), and this might be the factor to retard the development of the wilt symptoms.

As a whole it was generally concluded that Riga variety showed far higher wilt percentage than Minami variety at the soil temperatures lower than 30°C., but above 30°C. the wilt percentages decreased more conspicuously in Riga variety than in Minami variety. In other words, Minami variety is highly resistant to the wilt disease at comparatively low soil temperatures, but above 30°C. it is less resistant than Riga variety.

It is a noticeable point that the maximum outbreak of the wilt disease took place in both varieties at 30°C. In Riga variety all the plants were frequently annihilated at soil temperatures above 23°C., and at 30°C. they were utterly killed within the shortest time, while in Minami variety the seedlings were annihilated just at 30°C. in general, and at the other soil temperatures some plants remained unaffected, with an exception in experiment No. 6, in which Minami variety was annihilated at 33°C. and 35°, with more prolonged time length than in the case at 30°C. From these results it is clear that the apparent optimum soil temperature for the occurrence of the wilt-disease is 30°C. for both Minami and Riga varieties.

IX. Studies on some physiological characters of Minami variety in comparison with Riga variety

(1) Studies of plasmolysis.

Several studies have been published concerning the protoplasmic peculiarity in relation to disease resistance and immunity. Especially on the resistance of flax to the wilt, TISDALE (1917a) stated that in certain cases resistance is due to some chemical substances being comprised in the protoplasm which is injurious to the growth of the pathogene. REYNOLD (1931) said that flax contains a special glucoside, linamarine, which produces HCN by hydrolysis, and on analysing extracts from flax stems, there was found remarkable difference in the amount of HCN. Flax which contains much of it, generally shows higher resistance than others. From this fact he concluded that the existence of this glucoside should have close connection with an active wilt resisting function of cells of flax at the seedling stage.

Concerning the protoplasmic difference in plants WEBER (1930) said that some plants which are hardly different in morphological aspect can clearly be distinguished by the difference in types of plasmolysis.

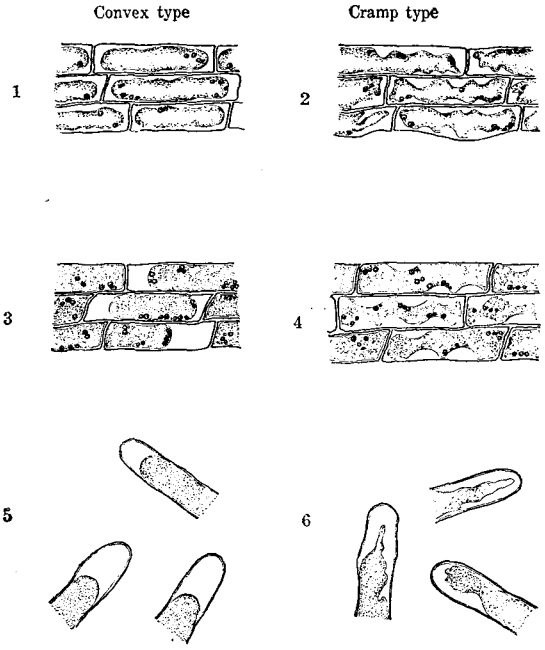
The writer has carried out several experiments in order to examine whether or not there is any difference in the characters of protoplasm between Minami and Riga variety.

In raising experimental plants, water cultures and pot cultures in a soil temperature tank were used. In the case of pot cultures, sterilized soil was used, and the soil moisture was regulated by auto-irrigators. The two varieties were planted side by side in separate halves of the same pot for the purpose of a comparison under the same conditions. For the examination of root hairs, seeds of both varieties were germinated and grown a few days on wet blotting paper on the same glass germ-plate. From the result of the writer's experiment (1933) the most favorable hydrogen-iron concentrations of cultural solution for flax was known to be pH 4.8–5.4, which were prepared by the prescription shown in Table 26. In the course of the experiment the hydrogen-iron concentration of the cultural solution was measured every day, and if it changed beyond a certain limit, the solution was renewed immediately.

TABLE 26. Composition of the cultural solution.

Solution A		Solution B (Knop's solution)	Total amount	Hydrogen-ion concentration
M/5 NaH_2PO_4	M/5 Na_2HPO_4			
c.c. 491.5	c.c. 8.5	c.c. 500	c.c. 1000	pH 4.8
482.0	18.0	500	1000	pH 5.2
472.5	27.5	500	1000	pH 5.4

For the water culture cylindrical hard glass jars of 6 cm. diameter and 20 cm. depth were used. Seedlings were raised in a sterilized fine sand bed, and when young roots had grown about



Text-fig. XIX. Showing plasmolytic types.

1 and 3 show convex plasmolysis in epidermal and subepidermal cells of hypocotyl.
2 and 4 show cramp plasmolysis in epidermal and subepidermal cells of hypocotyl.
5 shows convex plasmolysis in root hair.
6 shows cramp plasmolysis in root hair.

1–2 cm., they were inserted in the culture solution through the holes of thick paraffin paper covers. When the shoots (the part above the cotyledon) had grown about 3 cm. the epidermis with root hairs was peeled off and used for observation of the plasmolytic types. As plasmolytica, the solutions of potassium nitrate, glycerine and sugar were tried. In this experiment 0.3–0.5 mol sugar solution brought the best results.

According to the present observation, two different plasmolytic types, the so-called "convex plasmolysis" and "cramp plasmolysis" after WEBER could be clearly distinguished (cf. Text Fig. XIX and Plate XI).

a. Comparison of plasmolytic types in Minami and Riga varieties.

By means of the above described method, plasmolytic types of Minami and Riga varieties were observed in the cells of hypocotyls and root hairs, and the frequency of the occurrence of either plasmolytic type was compared. The results are given in the following table.

TABLE 27. Types of plasmolysis observed in Minami and Riga varieties.

Variety	Type of plasmolysis	Root hair		Hypocotyl	
		Total number	Percentage	Total number	Percentage
Minami	Cramp type	78	89.66	108	72.73
	Convex type	9	10.34	40	27.27
Riga	Cramp type	11	12.94	37	26.62
	Convex type	74	87.06	102	73.38

As shown in the above table, a difference in the principally occurring plasmolytic types in Minami variety and Riga variety could be clearly recognized, i.e., in Minami variety the cramp plasmolysis occurred more frequently, and on the contrary, in Riga variety the convex plasmolysis occurred in a majority of cases.

b. Comparison of plasmolytic types in Minami and several susceptible varieties.

The present experiments were carried out in order to examine the types of plasmolysis in Minami, Riga and 12 other susceptible varieties which are cultured in the experimental farm of the Hokkaido Imperial University. Materials were cultured in pots.

TABLE 28. Results of comparative observation of types of plasmolysis occurring in the resistant Minami variety and susceptible Riga and other varieties.

Varieties	Number of observations	Types of plasmolysis			%tage of cramp plasmolysis in 13 suscept. vars. to that in Minami var.
		Type(1)	Actual number	%tage	
Minami	74	M Type O ,,	54 20	72.97 27.03	100.00
Russia	63	M ,, O ,,	22 41	34.92 65.08	47.85
France	50	M ,, O ,,	17 33	34.00 66.00	46.60
Ichigoshu	50	M ,, O ,,	16 34	32.00 68.00	43.85
Chokeishu	95	M ,, O ,,	27 68	28.42 71.58	38.95
Belgium	43	M ,, O ,,	12 31	27.91 72.09	38.25
London	58	M ,, O ,,	16 42	27.59 72.41	37.81
Holland	66	M ,, O ,,	18 48	27.28 72.72	37.39
Odessa	83	M ,, O ,,	22 61	26.51 73.49	36.33
Riga	76	M ,, O ,,	19 57	25.00 75.00	34.26
Dutch	49	M ,, O ,,	12 37	24.49 75.51	33.56
Hokkaido zairaishu	79	M ,, O ,,	17 62	21.52 78.48	29.49
Shinkoku ama	65	M ,, O ,,	12 53	18.46 81.54	25.30
Pernau	82	M ,, O ,,	12 70	14.63 85.37	20.05

(1) M type indicates cramp plasmolysis and O type convex plasmolysis.

Minami and one of the others varieties were cultured side by side in every half of a pot under practically identical conditions. For observation the middle part of the hypocotyls of seedlings showing equal growth, was used, and the experimental method was just the same as in the previous experiment. The results of the comparative observation are given in Table 28.

As shown in the above table, cramp plasmolysis was by far the most frequent in occurrence in Minami variety, while in all other flax varieties examined the convex plasmolysis was found in the majority with no exception. From these results it was clear that Minami variety has a cytoplasmic character in respect to plasmolytic type entirely different from any other variety examined.

c. Relation of soil temperature to plasmolytic type.

From the results obtained in the previous experiments it was ascertained that the soil temperature has an important relation to the occurrence of the wilt disease of flax. Minami variety which is strongly resistant to the wilt disease at low soil temperature was severely affected at temperatures above 30°C. and susceptible Riga variety showed somewhat stronger resistance to the disease than Minami variety at high soil temperatures. These facts suggested that soil temperature somehow influences the fundamental nature of the wilt resistance in flax. A remarkable difference in plasmolytic types predominated in resistant Minami variety and susceptible Riga and other flax varieties having been found, it seemed of interest to examine whether or how the soil temperatures influence the plasmolytic types of the flax varieties holding the connection with the wilt resistance and susceptibility in mind. From this viewpoint the next investigations were undertaken.

Experiment No. 1.

Experimental plants were cultured in pots which contained sterilized soil kept under as nearly identical conditions as possible. The soil temperature was regulated at 10°, 18°, 20°, 23°, 26° and 30°C. by the help of a soil temperature tank, and the soil moisture was kept at about 41% by means of an auto-irrigator. Two pots each were used for every experimental plot. From 25 to 30 grains

of sterilized seeds of Minami and Riga varieties were sown separately in the two halves of a pot. When the shoots had grown about 3 cm., the frequency of the appearance of cramp or convex plasmolysis in the cells of the hypocotyl, using 0.3 mol sugar solution as plasmolyte, was observed. The results of the observations are given in Table 29.

TABLE 29. Frequency of the two types of plasmolysis in relation to different soil temperatures occurring in Minami and Riga varieties.

Temperature (C)	Number of observations	Type	Actual Number	%-tage	Difference	Number of observations	Type	Actual Number	%-tage	Difference
10°	99	M	56	56.57	+13.14	116	M	32	27.59	−44.82
		O	43	43.43			O	84	72.41	
18°	72	M	44	61.12	+22.24	49	M	18	36.73	−26.54
		O	28	38.88			O	31	63.27	
20°	44	M	27	61.36	+22.72	110	M	30	27.27	−45.46
		O	17	38.64			O	80	72.73	
23°	84	M	56	66.67	−33.34	120	M	36	30.00	−40.00
		O	28	33.33			O	84	70.00	
30°	13	M	6	46.15	− 7.70	29	M	20	68.97	+37.94
		O	7	53.85			O	9	31.03	

M type means cramp plasmolysis and O type means convex plasmolysis.
" + " indicates superfluous percentage of cramp type over convex type.
" − " indicates superfluous percentage of convex type over cramp type.

The results indicate a striking influence of soil temperature on the predominant type of plasmolysis. Below 23°C. in Minami variety the cramp type always predominated over the convex type, and in Riga variety on the contrary the convex type exceeded the cramp type with no exception below the same temperature. At 30°C., however, the convex type slightly exceeded the cramp type in Minami variety and the cramp type remarkably predominated over the convex type in Riga variety. The situations of Minami variety and Riga variety in regard to plasmolytic types were just the reverse at 30°C. and 23°C. soil temperature. For the confirmation of this experiment, the next one was carried out.

Experiment No. 2.

In this experiment the soil temperature was regulated at 10°, 16°, 20°, 23°, 26°, 30°, 33°, 35°, 38°, 40° and 45°C. and other environmental factors and experimental methods were similar to the previous one. Thirty grains each of sterilized seeds were sown side by side in the respective halves of each pot, and observations of plasmolysis were made with seedlings which had grown 15–16 days after emergence. The summarized results of the experiment are shown in Table 30 and Text Fig. XX.

TABLE 30. Showing the frequency of the two types of plasmolysis in relation to the different soil temperatures in comparison of Minami and Riga varieties.

Temperature (C)	Minami variety					Riga variety				
	Number of observations	Type	Actual Number	%-tage	Difference	Number o observations	Type	Actual Number	%-tage	Difference
10°	299	Mtype	171	57.19	+14.38	358	Mtype	187	52.24	+ 4.48
		O ,,	128	42.81			O ,,	171	47.76	
16°	138	M ,,	79	57.24	+14.48	179	M ,,	63	35.09	−29.82
		O ,,	59	42.76			O ,,	116	64.91	
20°	189	M ,,	131	69.32	+38.64	303	M ,,	114	37.63	−24.74
		O ,,	58	30.68			O ,,	189	62.37	
23°	155	M ,,	89	57.42	+14.84	254	M ,,	79	31.11	−37.78
		O ,,	66	42.58			O ,,	175	68.89	
26°	234	M ,,	127	54.27	+ 8.54	350	M ,,	132	37.72	−24.56
		O ,,	107	45.73			O ,,	218	62.28	
30°	204	M ,,	63	45.00	−10.00	148	M ,,	83	49.11	− 1.78
		O ,,	77	55.00			O ,,	86	50.89	
33°	247	M ,,	134	54.26	+ 8.51	178	M ,,	88	49.43	− 1.14
		O ,,	113	45.74			O ,,	90	50.57	
35°	239	M ,,	113	47.29	− 5.42	458	M ,,	255	55.68	+11.36
		O ,,	126	52.71			O ,,	203	44.32	
38°	233	M ,,	56	24.04	−51.92	186	M ,,	108	58.06	+16.12
		O ,,	177	75.96			O ,,	78	41.94	
40°	219	M ,,	62	28.32	−43.36	274	M ,,	172	62.77	+25.54
		O ,,	157	71.68			O ,,	102	37.23	
45°	150	M ,,	55	36.66	−26.68	154	M ,,	90	58.44	+16.88
		O ,,	95	63.34			O ,,	64	41.56	

M type means cramp plasmolysis and O type means convex plasmolysis.
"+" indicates superfluous percentage of cramp type over convex type.
"−" indicates superfluous percentage of convex type over cramp type.

Text-fig. XX. Curves showing the variation in occurrence of cramp plasmolysis comparing Minami and Riga varieties in relation to change of soil temperature.

The results obtained in the present experiment are fundamentally homologous with those of the previous one. In Minami variety, in the plants which had grown at low soil temperatures below 26°C., cramp plasmolysis occurred more frequently than convex plasmolysis, and in plants grown at 30°–35°C. cramp and convex plasmolysis took place with small disparities in frequency, but in plants grown at the soil temperatures over 38°C. the convex plasmolysis remarkably exceeded the cramp plasmolysis; while again there appeared a tendency to a slight gain in the percentages of cramp plasmolysis at 40° and 45°C. In Riga variety, however, in the plants which had grown at the low soil temperatures below 26°C. convex plasmolysis occurred far more frequently than cramp plasmolysis, at

30° and 33°C. both types were observed almost equally in plasmolysis, and at the soil temperatures above 35°C. cramp plasmolysis distinctly predominated over convex plasmolysis.

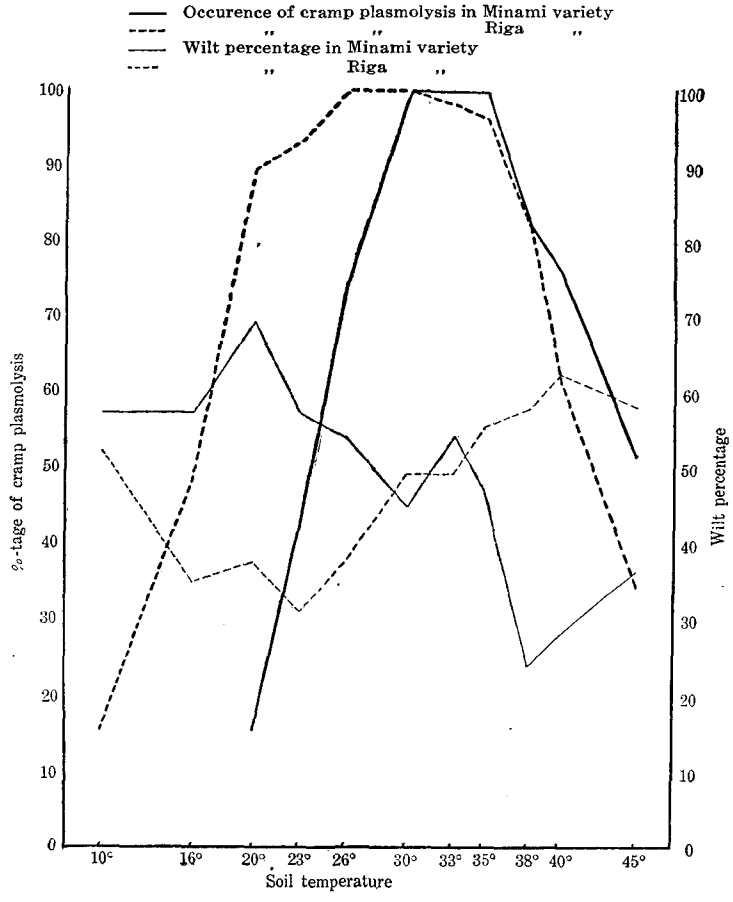
From these results, it seems that the relations of soil temperature to the occurrence of the wilt disease and to the types of plasmolysis are very suggestive and interesting. To examine these relations closely, the data on types of plasmolysis obtained in the present experiment were collated to those of the wilt occurrence in experiment No. 6 described above in section VIII. As the types of plasmolysis were observed in the seedlings after 15–16 days from their emergence, the data obtained of equally old seedling in experiment No. 6 in chapter VIII, which are shown in Tables 23 and 24, were compared in the next table and in the text figure.

TABLE 31. Showing the frequency of cramp plasmolysis and the occurrence of the wilting by percentage in Minami and Riga varieties in relation to the change of soil temperatures after 16 days from emergence.

Soil temperature (C)	Percentage of occurrence cramp plasmolytic type to total plasmolysis		Percentage of wilting	
	Minami	Riga	Minami	Riga
10°	57.19	52.24	0	15.25
16°	57.24	35.09	0	48.33
20°	69.32	37.63	15.25	89.83
23°	57.42	31.11	42.37	93.33
26°	54.27	37.72	74.14	100.00
30°	45.00	49.11	100.00	100.00
33°	54.26	49.43	100.00	98.31
35°	47.29	55.68	100.00	96.67
38°	24.04	58.06	82.46	82.46
40°	28.32	62.77	76.36	61.40
45°	36.66	58.44	51.72	34.48

From Table 31 and the curves in Text Fig. XXI, it is noticed that in Minami variety, at the soil temperatures ranging from 20°C. to 30°C., in which the wilt percentages increased gradually from 15% up to 100%, the frequency of cramp plasmolysis decreased

reversely; while in Riga variety, at the range of soil temperatures from 10°C. to 26°C., in which gradual increase of the wilt percentage from 15% up to 100% occurred, the frequency of cramp plasmolysis showed distinctly much lower than that of Minami variety, and also



Text-fig. XXI. Curves showing the variations in occurrence of cramp plasmolysis and the wilt disease in Minami and Riga seedlings after 16 days from emergence in relation the change of soil temperature.

showed a decrease with respect to the soil temperatures. These could be considered as suggestive data on the relation between the difference in character of plasmolysis and the occurrence of wilt.

On the relation between viscosity of protoplasm and plasmolysis type, WEBER concluded from his studies (1924, 1925) with Spirogyra that viscosity of protoplasm could be distinguished according to three types of plasmolysis, viz. convex, polygonal and cramp plasmolysis correlated respectively to low, intermediate and high viscosity of protoplasm. He said that the difference in type of plasmolysis depends upon the colloidal character of protoplasm membrane, and that the viscosity of exterior and interior of protoplasm was always correlative.

It was a conspicuous phenomenon that the wilt resistance of MINAMI variety was very strong at the soil temperatures lower than 30°C., at which cramp type predominated over convex type plasmolysis. At 30°C., however, Minami variety showed no species resistance to the wilt, and above that temperature suddenly it became rather more susceptible than Riga variety, and in seedlings of Minami variety grown at the soil temperatures above 30°C. the convex plasmolysis remarkably exceeded the cramp plasmolysis.

From these facts it is to be concluded that the nature of cytoplasm, which presents more cramp type than convex in plasmolysis, would have close connection with the wilt resistance in flax.

(2) Studies on anti-toxicity of Minami variety to certain salt solutions in comparison with Riga variety.

It has been reported by many investigators that different kinds of plants show differences in anti-toxicity to the solutions of certain salts, but further studies in this line on the varietal differences in the same crop have been reported only by HARTER (1905), KEARNEY and HARTER (1907) and YAMAZAKI (1929). HARTER experimented on wheat, KEARNEY and HARTER on corn and rye, and they clearly recognized varying anti-toxicities to the same salts according to the difference of varieties. YAMAZAKI studied the differences of anti-toxicity to $KClO_3$ solution between paddy and upland rice plants, hulled and naked barley, and among varieties of wheat. He recognized that the anti-toxicity of upland rice plant, hulled barley and early varieties of wheat to $KClO_3$ solution is stronger than that of paddy rice plant, naked barley and late varieties of wheat.

He explained these findings by saying that the differences of anti-toxicity in rice plant, barley and wheat varieties should not

be attributed to the difference of the cell-sap concentration, but to the characters preventing the permeation of the toxic substance into cells.

In the present studies the writer examined the difference of the anti-toxicity between Minami and Riga varieties to two kinds of salts, viz., $MgSO_4$ and Na_2CO_3. After being first sterilized with 1% aqueous solution of corrosive sublimate seeds were germinated on sterilized sand bed. When the young roots became about 5 cm. long, the plants were transplanted into water. After 7 days when the young shoots grew about 1 cm., they were again transplanted to the test solution in test tubes and glass vessels 6 cm. in diameter and 20 cm. in height. All vessels were covered with black paper to keep the roots from light. Salt solutions were prepared in series

TABLE 32. Results of comparative experiments on the antitoxicity of Minami and Riga varieties to $MgSO_4$.

Concentration (%)	Variety	Total number	Number of injured individuals (A), %-tage of the injured (B)	Days after transplanting								
				6	7	8	9	10	11	12	13	14
1.0	Minami	12	A	1	2	3	7	10	10	11	11	12
			B	8.33	16.67	25.00	58.33	83.33	83.33	91.67	91.67	100.00
	Riga	12	A	0	0	0	0	0	1	3	3	3
			B	0	0	0	0	0	8.33	25.00	25.00	25.00
0.8	Minami	12	A	0	0	3	5	9	12			
			B	0	0	25.00	41.67	75.00	100.00			
	Riga	12	A	0	0	3	3	3	3	5	5	7
			B	0	0	25.00	25.00	25.00	25.00	41.67	41.67	58.33
0.6	Minami	12	A	0	0	0	1	1	6	10	11	12
			B	0	0	0	8.33	8.33	50.00	83.33	91.67	100.00
	Riga	12	A	0	0	0	0	0	0	2	2	2
			B	0	0	0	0	0	0	16.67	16.67	16.67
0.4	Minami	12	A	0	0	0	0	0	2	5	6	8
			B	0	0	0	0	0	16.67	41.67	50.00	66.67
	Riga	12	A	0	0	0	0	0	0	0	0	2
			B	0	0	0	0	0	0	0	0	16.67
0.2	Minami	12	A	0	0	0	0	0	0	1	1	2
			B	0	0	0	0	0	0	8.33	8.33	16.67
	Riga	12	A	0	0	0	0	0	0	0	0	0
			B	0	0	0	0	0	0	0	0	0

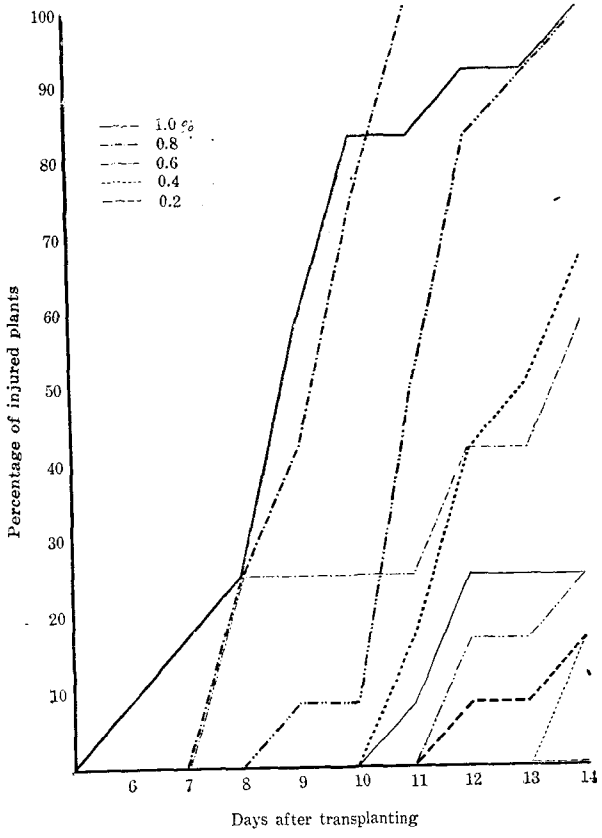
TABLE 33. Results of comparative experiments on the antitoxicity of Minami and Riga varieties to Na_2CO_3.

Concentration (%)	Variety	Total number	Number of injured individuals (A), & %-tage of the injured (B)	Days after transplanting						
				2	3	4	5	6	7	8
0.40	Minami	48	A	2	5	15	35	48		
			B	4.17	10.42	31.25	72.92	100.00		
	Riga	46	A	0	3	33	45	46		
			B	0	6.52	71.74	97.83	100.00		
*0.30	Minami	48	A	0	1	2	11	36	46	48
			B	0	2.08	4.17	22.92	75.00	95.83	100.00
	Riga	48	A	0	3	17	45	48		
			B	0	6.25	35.42	93.75	100.00		
0.20	Minami	48	A	0	0	4	4	9	28	47
			B	0	0	8.33	8.33	18.75	58.33	97.92
	Riga	48	A	0	5	13	13	30	44	48
			B	0	10.42	27.08	27.08	62.50	91.67	100.00
0.15	Minami	48	A	0	0	0	0	1	1	9
			B	0	0	0	0	2.08	2.08	18.75
	Riga	45	A	1	1	7	7	24	42	45
			B	2.22	2.22	15.56	15.56	53.33	93.33	100.00
0.10	Minami	48	A	0	0	0	0	1	1	8
			B	0	0	0	0	2.08	2.08	16.67
	Riga	48	A	0	0	0	4	14	28	
			B	0	0	0	8.33	29.17	58.33	

of 0.4, 0.3, 0.2, 0.15, 0.1% for Na_2CO_3 and 1.0, 0.8, 0.6, 0.4, 0.2% for $MgSO_4$. As to the methods for examining the anti-toxicity of plants to a certain salt solution, several measures have been recommended by various investigators in this line. In the present experiments the method was adopted of finding the critical concentrations of these salts at which the plants died as the result of injury within a certain period. Three plants were set in each test tube, and four tubes were used in each plot, or 24 plants were set in each glass vessel, and two vessels were used in each plot. The symptoms of intoxication appeared three days after setting into the salt solutions. Firstly the cotyledons turned from bright green color to gray or dark green, and the margin of the leaf curled up. This discoloration proceeded, and the cotyledons became dry and appeared to be wavy. The morbid changes gradually advanced to the upper leaves

until the stem became withered and the twigs hung down, and soon the entire plant died. (cf. Pl. XII & XIII). The results of this experiment are presented in Tables 32 and 33, and Text Figs. XXII and XXIII.

From the results obtained in the present experiments it was concluded that in respect to anti-toxicity to magnesium sulphate

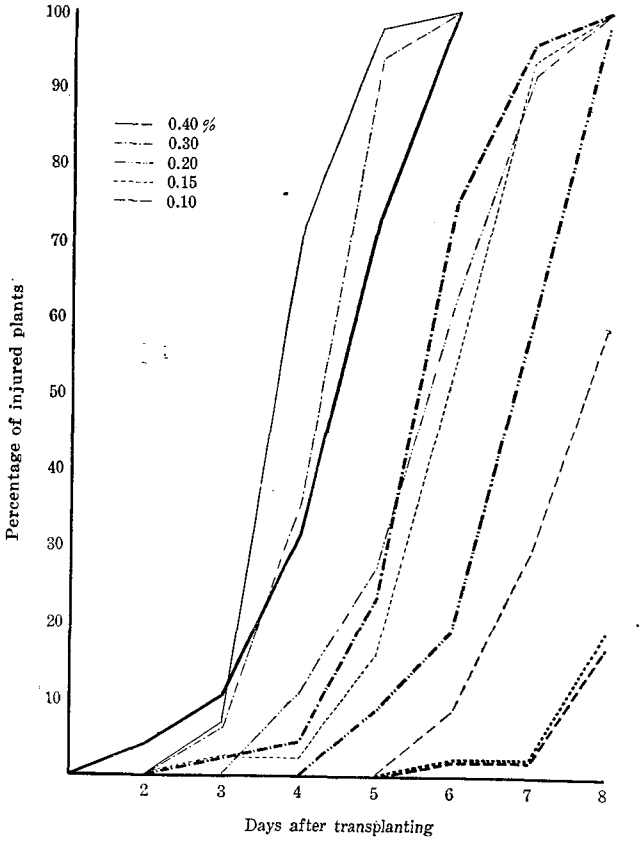


Text-fig. XXII. Curves showing the percentages of injured plants in Magnesium sulphate solution of varying concentrations. (Thick lines—Minami, fine lines—Riga.)

and sodium carbonate there is a marked difference between Minami and Riga varieties. To magnesium sulphate Minami variety was more resistant than Riga variety, while the situation of these two varieties was quite the reverse in relation to the sodium carbonate solution so far as the present concentrations are concerned.

(3) Sugar content in flax seedlings.

It has been known that the susceptibility of plants to diseases sometimes has close relation to their sugar content. A majority of previous investigators in this line recognized an increase of susceptibility concomitant with greater sugar content, for instance



Text-fig. XXIII. Curves showing the percentages of injured plants in Sodium carbonate solution of varying concentrations. (Thick lines—Minami, fine lines—Riga.)

TISCHER (1911) in the rust of Euphorbia cyparissias caused by *Uromyces Pisi* (Pers.) Wint., FAES and STAEHELIN (1923) in the fruit rot of grapes caused by *Coniothyrium diplodiella* (Speg.) SACC., and KRISTOFFERSON (1921) in the rot of Daucus Corota L. caused by *Phoma sanguinolenta* Rostr. and some *Botrytis*-forms. On the

other hand VIALA and PACOTTET (1904) said that in the black rot of grapes caused by *Guignardia Bidwellii* (Ell.) VIALA et RAV. the susceptibility was decreased by an accumulation of sugar and diminution of acid.

The writer examined the amount of sugar in seedlings of Minami variety and Riga and seven other susceptible varieties Russia, Holland, London, Odessa, Chokeishu, Ichigoshu and Shikokuama. Seedlings of every variety were raised under practically the same conditions, and in each pot Minami and one of the other varieties was planted side by side. In the comparative examination of Minami and Riga varieties 152 seedlings grown to about 3 cm. were used, and in the comparisons of Minami variety and each of the other susceptible varieties from 21 to 30 seedlings grown to about 5–6 cm. were used. The sugar content of Minami and Riga varieties was compared micro-chemically with Molisch's α-naphthol sulphuric acid color reaction. The amounts of invert sugar of Minami variety and each of the other seven susceptible varieties were compared by SACH's reaction with copper sulphate, and MEYER's reaction with ROCHELLE salt and caustic soda. In practice, cross sections of the hypocotyl of Minami and one of the other susceptible varieties were put on every slide glass side by side and treated simultaneously with the reagents, and the relative amounts of sugar were compared by noting the quickness of the discoloration. In most cases the discoloration of the reagents owing to the existence of sugar was slower in Minami variety than in the susceptible varieties examined with the sole exception of variety Holland. Experimental results are shown in the following Tables 34 and 35.

From these results, it was concluded generally that the amount of sugars in the tissues of hypocotyl of Minami variety was less than in Riga and other susceptible varieties.

Of course, it is not an easily solvable question whether the wilt resistance in Minami variety is directly attributable to the small amount of sugar or not. But it is suggested by TOCHINAI's (1926) pathological interpretations respecting the rapid wilting of flax seedlings, that remarkable gas production in decomposition of sugars by the causal fungus possibly causes interception of the ascent of sap. The low sugar content in Minami variety may have some relation to its wilt-resistance.

TABLE 34. Results of the comparative examination of the amount of sugar in seedlings of Minami and Riga varieties by means of Molisch's reaction.

Experimental plot	Actual number of observations	Cases of lower sugar content in Minami var. than that of Riga var.	Cases of equal amount of sugar content in both varieties	Cases of higher sugar content in Minami var. than that of Riga var.	Uncertain cases
I	50	32	8	1	9
II	28	20	1	1	6
III	74	45	15	14	0
Total	152	97	24	16	15

TABLE 35. Results of comparative examination of the amount of invert sugar in seedlings of Minami variety and seven other susceptible varieties by means of Sach's & Meyer's reactions.

Variety	Actual number of observations	Cases of lower sugar content in Minami var. than that of other var.	Cases of equal amount of sugar content in both varieties	Cases of higher sugar content in Minami var. than that of other var.	Uncertain cases
Russia	22	20	2	0	0
Holland	30	10	2	12	6
Ichigoshu	25	20	3	0	2
London	21	20	1	0	0
Odessa	21	20	1	0	0
Chokeishu	21	20	0	1	0
Shinkokushu	22	20	2	0	0

(4) Water content in flax seedlings.

As to the relation of water content and the susceptibility of plants to diseases several reports have been published. SCHAFFNIT (1912) reported on the disease of rye kernels caused by *Fusarium nivale* Ces., that the infection of the pathogene occurred very easily in the young stage, when the water content was 30–35%, but when

grains ripened to yellowish colour they escaped from the attack of the pathogene. Respecting potato rot caused by *Fusarium oxysporum* Schlect., *F. Trichochecioides* Wollenw. and F. *radicicola* Wollenw., GOSS (1921) observed in comparative tests with new and old tubers that there is a distinct difference in the amount of rotting under the same conditions. The rotting was much more rapid and progressed much further in the old than in the new tubers. HARTER and WEIMER (1922) reported on their experiments on the infection of various vegetables and fruits by different species of Rhizopus. They tried 11 species of Rhizopus on 27 different hosts and concluded that some hosts (those low in water content) could be infected only by "well" method, but watery or juicy hosts were infected very easily by merely inserting the spores and hyphae into a wound made by a needle.

To examine whether there is any difference in water content between the resistant Minami variety and the susceptible Riga

TABLE 36. Showing the data obtained in comparative examinations of water contents of stems, hypocotyls and roots of Minami and Riga flax seedlings.

Portion of plants	Plot	Days after germination	Number of individuals examined	Minami				Riga			
				Length of stem(1)	Weight of fresh material	Weight of dried material	%-tage of water	Length of stem(1)	Weight of fresh material	Weight of dried material	%-tage of water
				cm	gr	gr		cm	gr	gr	
Stem	I	22	20	4.69	1.042	0.08	92.32	3.99	1.635	0.115	92.99
	II	29	20	8.09	1.162	0.100	91.39	6.27	2.084	0.173	91.70
	III	9	20	0.60	1.074	0.079	92.64	0.60	1.114	0.080	92.85
	IV	19	20	5.42	2.217	0.178	91.96	5.31	2.368	0.190	91.99
Hypocotyl(2)	V	8	35		0.503	0.033	93.51		0.490	0.027	94.49
	VI	10	35		0.651	0.047	92.83		0.613	0.048	92.12
Root(3)	VII	3	30		0.256	0.029	88.87		0.299	0.029	90.28
	VIII	4	30		0.447	0.049	88.93		0.531	0.055	89.62

(1) Measurements of stem from the first lateral root to tip.
(2) The part between the attached point of cotyledons and first lateral root.
(3) Parts below the colyledons.

variety at their seedling stage grown under practically identical conditions, the water content of their stems, hypocotyls and roots were compared in absolute weight. The results are shown in Table 36.

As shown in the above table, the percentages of the water content in Minami variety were generally more or less higher than those in Riga variety. Exceptionally, in Plot VI, Riga variety showed higher percentage of water content than Minami. As a whole, it is considered that the results of the present experiment are suggestive of a little similar tendency to SCHAFFNIT's and HARTER and WEIMER's results described above, but any significance which could be estimated was not found because the differences in the water contents were numerically very small.

(5) Hydrogen-ion concentration of cell sap in flax seedlings.

About the relation of hydrogen-ion concentration of cell sap of plants to their disease resistance or susceptibility, several studies have been reported by many authors. However, no decisive result to prove a positive relation has been advocated up to the present time. TIMS (1926) who studied the cabbage yellow caused by Fusarium conglutinans Wr. reported that the hydrogen-ion concentration of cell sap of resistant and susceptible cabbage varieties was estimated to range from pH 6.2 to pH 6.5, but it has no positive correlation to the disease resistance. MIYABE (1926), referring to the work of MIYAKE and ADACHI (unpublished) on the comparative chemical studies of the wilt resistant and susceptible flax varieties, suggested some possible relation between the wilt resistance and hydrogen-ion concentration of cell sap based upon a hydrogen-ion concentration in the resistant variety slightly higher than in other varieties.

The writer carried out some experiments in order to examine the hydrogen-ion concentration of cell sap in Minami and Riga varieties. Both varieties were raised side by side in the same pot or sown on the same glass germ plates to grow under practically identical conditions. The hydrogen-ion concentration was measured of the hypocotyl of the seedlings raised in pots and of the young roots of those germinated on glass plates. Fresh samples were quickly mashed in a mortar, and a few drops of the juice were gained for measuring hydrogen-ion concentration with quinhydron

electrode. Minami and Riga varieties were simultaneously treated and measured. The results are shown in Table 37.

TABLE 37. Showing the hydrogen ion concentration of the sap of young seedlings of Minami and Riga varieties.

Plant part	Number of experiment	Minami		Riga	
		pH	average	pH	average
Hypocotyl	1	5.15	5.42	5.07	5.32
	2	5.48		5.51	
	3	5.52		5.22	
	4	5.54		5.49	
Young root	1	6.21	6.07	6.27	5.93
	2	6.12		6.06	
	3	5.84		5.52	
	4	6.29		6.04	
	5	5.89		5.99	
	6	6.24		5.85	
	7	5.88		5.81	

The results of the experiments showed that the hydrogen-ion concentrations of cell sap in Minami and Riga varieties differ but very little, being in general slightly lower in Minami than in Riga variety with some exceptional cases. Considering the influence of *Fusarium Lini* upon hydrogen-ion concentration of the growth medium (cf. TOCHINAI, 1926), such slight differences in hydrogen-ion concentration of cell sap of the two varieties seem to have no direct correlation to their disease resistance or susceptibility.

(6) Osmotic pressure of cell sap in flax seedlings.

The present experiment was carried out to learn whether there is any difference in the osmotic pressure of cell sap between wilt resistant Minami variety and susceptible Riga variety by making measurements of the freezing point.

Materials were cultured in the same pots side by side under practically identical environmental conditions. When the shoots

had grown 3 cm. long they were cut off and subjected to low temperature, -10°C., -12°C., -16°C., and -25°C. for a certain length of time. Then they were well mashed in mortars and the juice was pressed out with the same pressure. The freezing point was measured by BECKMAN's thermometer. From this measured value the osmotic pressure was calculated by SAKAMURA's table (SAKAMURA, 1934, Osmotic physiology of plant cell). The results of the experiments were summarized in the following table.

TABLE 38. Showing the osmotic pressure of cell sap of Minami and Riga varieties.

Sample	5 hours subjection to −10°C.			4 hours subjection to −12°C.			1.5 hours sub ection to −25°C.			2 hours subjection to −26°C.		
	Actual reading of freezing point	Average	Osmotic pressure	Actual reading of freezing point	Average	Osmotic pressure	Actual reading of freezing point	Average	Osmotic pressure	Actual reading of freezing point	Average	Osmotic pressure
Distilled water	4.360			4.365			4.365			4.360		
	3.820			3.630			3.700			3 800		
Minami	3.850	3.840	6.266	3.625	3.632	8.739	3.690	3.693	8.071	3.810	3.805	6.747
	3.850			3.640			3.690			3.805		
	3.810			3.630			3.730			3.785		
Riga	3.780	3.800	6.747	3.660	3.630	8.793	3.725	3.725	7.710	3.735	3.773	7.103
	3.800			3.600			3.720			3.800		
Difference of average (Riga compared with Minami)			0.481			0			0.361			0.361

In some cases Minami variety showed slightly higher osmotic pressure than Riga variety, but in other cases it was quite the reverse. Thus it is to be concluded that there is hardly any difference in osmotic pressure of cell sap in Minami and Riga varieties.

(7) General conclusions to the experimental results with respect to some physiological characters of Minami variety in comparison with Riga variety.

Generally surveying the results obtained in the several studies which have been carried out on the physiological or physico-chemical

characters of wilt resistant flax variety Minami in comparison with the susceptible Riga variety, the following would be noticed.

In types of plasmolysis, these two varieties present a marked difference. As far as the results of the present experiments are concerned, two types of plasmolysis, viz., cramp and convex plasmolysis, occur in cells of flax seedlings, and the frequency in appearance of these types differs with varieties and with the soil temperatures at which the flax seedlings had grown. When the two varieties grew at soil temperatures below 20°C. Minami showed more cramp plasmolysis than convex, but on the contrary, in Riga variety, convex plasmolysis appeared more often than cramp plasmolysis. In seedlings grown at soil temperatures near 30°C., both types of plasmolysis appeared almost equally, and in seedlings grown at the soil temperatures above 30°C. viz., 35°C. etc., the appearance of these two types of plasmolysis was quite the reverse. In the seedlings grown at temperatures below 20°C. there appeared much convex plasmolysis and less cramp plasmolysis in Minami and much cramp plasmolysis and less convex plasmolysis in Riga variety. It is a very interesting fact that the wilt resistance of Minami variety was very strong at low soil temperature, but it was no longer any more resistant than Riga variety at high soil temperatures. It would be recognized that seedlings of Minami variety would be resistant to the wilt disease under the conditions in which the protoplasm presents more cramp plasmolysis than convex plasmolysis, and in the reverse plasmolytic condition they would be susceptible to the wilt-disease.

In comparative studies on anti-toxicity of Minami and Riga varieties to certain salts Minami variety showed more resistance to magnesium sulphate than Riga variety, while Riga variety showed a higher resistance to sodium carbonate than Minami variety. It is clear from this fact that the protoplasmic characters of these two varieties are quite different. In sugar content, water content, hydrogen-ion concentration and osmotic pressure of cell sap no remarkable difference was noticed between Minami and Riga varieties.

As a whole, it is concluded that the physico-chemical characters of Minami and Riga varieties are distinctly different with respect to the type of plasmolysis and to the resistance to some kinds of salt, and that these protoplasmic peculiarities of Minami variety may be connected closely with the wilt resistance.

X. Genetical studies on the inheritance of the wilt resistance

For the prevention of diseases of crops caused by parasites, the cultivation of so-called resistant varieties is one of the most important hygienic methods. A great number of studies on this subject have been carried out by many investigators. Especially on the resistance to wilt disease caused by Fusaria, important reports have been published by ORTON (1908) on cotton blight, by JONES and GILMAN (1915), JONES, WALKER and TISDALE (1920) and ANDERSON (1933) on cabbage yellow disease, and by ESSARY (1912) on tomato blight. Among these the reports of JONES and GILMAN (1915) and JONES and others (1920) are especially interesting. They selected some varieties of cabbage which were strongly resistant to cabbage yellows caused by Fusarium Conglutinans Wr. These varieties were selected from the individuals which showed strong resistance to the disease and survived on the field where the disease was prevalent. It was noticed that the resistance increased through continuous selection, but the wilt resisting character of these varieties seemed to be essentially relative and the development of the disease was influenced by environmntal factors, especially by soil temperature, owing to vicissitudes in the resistance of the host plant. They said that the resistance would be lessened to some extent if the selection were not repeated continuously in later generations in securing resistant plants.

There are several reports of genetical works on resistance of flax to the wilt disease. Prior to these a pioneer work was done by BROEKEMA (1893) who first distinguished this wilt disease from others which had been called by the vague terms (Brand, or "Vlasbrand", recognized the destructiveness of the disease and suspected that it was caused by a parasite. He found resistant individuals which remained healthy in the wilt ravaged flax field. He was sceptical whether the resistant character might be hereditary or not, while he found no apparent morphologic difference between the resistant individuals and ordinary others, and he cultivated flax plants with the seeds obtained from the resistant plants to compare them with ordinary ones. As the results of the experiments he obtained some resistant plants grown from the selected seeds. He explained this fact by stating that the resistant individuals have

a certain disposition to grow vigorously, and consequently they stand out against an attack of the disease owing to their strong vitality. This explanation seems to attribute the resistance to a particular physiological character of the host plant. BOLLEY (1903, 1907) selected wilt resistant flax plants by cultivating ordinary market seeds, on soil inoculated with Fusarium Lini BOLLEY, and he said that these resistant plants would lose their resistance by continuous cultivation on clean soil.

Since BIFFEN (1905, 1907) reported the Mendelian inheritance of rust resistance in wheat, a large number of studies on this line have been made from the standpoints of plant breeding as well as of plant pathology. In 1912 BOLLEY reported his work on controlling flax wilt by breeding resistant varieties. TISDALE (1917a) stated that the wilt resistance of flax is a heritable character depending upon multiple factors. In the Minnesota Agricultural Experimental Station, STAKMAN et al. (1919) made experiments confirming BOLLEY's studies reported in 1903 and 1907. HAYES and GARBER (1921), however, said that it is not clear whether the resistance would be lost in cultivation on clean soil which contains no pathogene, and also whether the appearance of resistance is due to spontaneous internal change. Later on BARKER (1923) and BURNHAM (1932) carried out some genetical studies about the wilt resistance of flax and stated that the inherited wilt resisting character is revealed in various grades influenced by environmental conditions.

Since 1934, the writer has made some genetical experiments to examine the inheritance of the wilt-resistant character of Minami variety in crossing with other flax varieties. The experiments were carried out in the following two sections:

(1) Crossing of Minami variety with Riga variety and of its reciprocal.
(2) Crossing of Minami variety with some susceptible varieties other than Riga variety.

(1) Minami × Riga and its reciprocal.

(a) Inheritance of the wilt resistance in F_1 generation.

Parents were cultured on clean soil and crossing was done in a green house. For the examination of the wilt resistance in F_1

plants, some number of the F_1 individuals were raised on sick soil. The other F_1 individuals were cultured on clean soil to grow F_2 generation. As a check plot the parental varieties were cultured under the same conditions. The entire course of the experiment was accomplished in a greenhouse at 16°–20°C.

The results obtained in observing the occurrence of the wilt in F_1 plants and their parents are summarized in the next table.

TABLE 39. Occurrence of the wilt in F_1 generation of Minami × Riga. (1934).

Strains and combinations	Total number of plants	After 2 weeks from emergence		Wilt percentage	After 4 weeks from emergence		Wilt percentage
		Number of healthy individuals	Number of wilted individuals		Number of healthy individuals	Number of wilted individuals	
Minami	30	28	2	6.76	27	3	10.00
Riga	30	5	25	80.30	3	27	90.00
Minami × Riga	16	14	2	12.50	13	3	18.75
Riga × Minami	28	23	5	17.85	22	6	21.43

The wilt percentages observed in the present experiments were 10% in the resistant parent Minami variety, 90% in the susceptible parent Riga variety, 18.75% in F_1 plants of Minami × Riga and 21.43% in F_1 plants of Riga × Minami after 4 weeks from emergence. It was a noticeable fact that the wilt percentages in F_1 generations were a little higher than those of the resistant parent but they were remarkably lower than those of the susceptible one.

Taking the mean value of the wilt percentages of Minami and Riga varieties at four weeks, i.e., 50%, and comparing it with the mean wilt percentages of F_1 generation, the latter is seen to be distinctly lower. In other words, the wilt resistance of the resistant parent Minami variety seems obviously to be inherited as a dominant character by F_1 generation. Then it should be an interesting problem how the wilt resistance will be inherited by F_2 generation and will segregate in descendants of this hybrid later on.

(b) Inheritance of the wilt resistance in F_2 generation.

F_1 plants obtained by crossing Riga and Minami varieties were cultured on clean soil and allowed to produce seeds by self pollination. In the next year the seeds of each line were planted separately on sick soil in pots. They were raised outdoors in the daytime and kept in the greenhouse of 16°–20°C. at night. The data obtained by observations on the occurrence of the wilt are shown in Tables 40 and 41.

TABLE 40. Occurrence of the wilt in F_2 generation of Riga × Minami. (1935).

F_2 Strains		Total individuals	Healthy individuals	Wilted individuals	Wilt percentage
Riga		36	2	34	94.44
Minami		60	54	6	10.00
Riga × Minami	-1-1	53	29	24	45.28
	1-2	74	34	40	54.05
	1-3	39	23	16	41.03
	1-4	42	41	1	2.38
,,	-2-1	35	23	12	34.29
	2-2	50	32	18	36.00
	2-3	50	16	34	68.00
	2-4	50	48	2	4.00
	2-5	29	29	0	0
,,	-3-1	58	35	23	39.66
	3-2	62	22	40	64.52
	3-3	50	12	38	76.00
	3-4	29	28	1	3.45
	3-5	74	26	48	64.86
	3-6	50	48	2	4.00
,,	-4-1	40	7	33	82.50
	4-2	30	4	26	86.67
	4-4	49	42	7	14.29
	4-5	41	41	0	0
,,	-5-1	46	37	9	19.57
	5-2	42	35	7	16.67
	5-4	41	39	2	4.88

TABLE 41. Occurrence of the wilt in F_2 generation of Minami × Riga,

F_2 Strains		Total individuals	Healthy individuals	Wilted individuals	Wilt percentage
Minami		59	52	7	11.86
Riga		49	6	43	87.76
Minami×Riga	-1-1	7	7	0	0
	1-2	8	5	3	37.50
	1-3	82	28	54	65.85
	1-4	10	5	5	50.00
,,	-2-1	76	9	67	88.16
	2-2	23	10	13	56.52
	2-3	24	21	3	12.50
	2-4	8	8	0	0
	2-5	23	23	0	0
	2-7	17	17	0	0
,,	-3-1	17	12	5	29.41
	3-2	16	16	0	0
	3-3	13	13	0	0
	3-4	14	11	3	21.43
	3-5	9	9	0	0
,,	-4-1	77	23	54	70.13
	4-2	15	15	0	0
	4-3	6	6	0	0
	4-4	19	17	2	10.53
,,	-5-1	26	26	0	0
	5-2	22	22	0	0
	5-3	21	21	0	0
,,	-6-1	7	7	0	0
	6-2	20	11	9	45.00
	6-3	9	9	0	0
	6-4	10	10	0	0
	6-5	23	23	0	0
	6-7	24	24	0	0
	6-8	28	23	5	17.86
,,	-7-2	21	6	15	71.43
	7-3	9	9	0	0
	7-4	12	12	0	0
	7-5	7	7	0	0

In the crossings of Riga × Minami and Minami × Riga, it is noticeable that the number of resistant F_2 lines was distinctly greater than the susceptible ones. Taking the mean value of wilt percentages of the resistant and susceptible parents, to which those of every F_2 line were compared respectively, among the 33 lines of Minami × Riga, 27 lines showed lower and 6 lines showed a little higher percentages in comparison with the mean value of wilt percentage of the resistant and susceptible parents. Among 22 lines of the reciprocal crossing, wilt percentages of 15 lines were lower and those of 7 lines were a little higher than the mean value.

Making a more detailed examination on the wilt percentage in each line, a few of them are found to show wilt percentages relatively near to the susceptible parent, but most of them show far less susceptibility than the latter, and some lines show none of the wilting as far as the individuals in this experiment are concerned. Especially in F_2 plants of Minami × Riga frequent appearances of non-wilted lines are observed. It is ascertained from these results that the wilt-resisting character of Minami variety is inherited strongly in some F_2 lines. In general survey of F_1 and F_2 populations, it is concluded that the wilt resisting character of Minami variety is inherited mixed with the wilt susceptible character of the other parent in F_1 crossing, and these characters segregated in F_2 population with the result that susceptible, intermediate and resistant descendants are produced.

(2) Crossings of Minami variety with several susceptible varieties.

(a) Inheritance of the wilt resistance in F_1 generation.

Experiments were carried out through 1934–1936 to learn how heritable the wilt resistance of Minami variety may be in crosses with certain other susceptible varieties. As materials 13 widely grown varieties of flax were used in crossings with Minami variety. Firstly the susceptibility of these non-resistant varieties to the wilt was examined in comparison with Minami variety, and secondly the wilt resistance of the F_1 plants was examined by growing on sick soil. The results of those examinations are given in Tables 42 and 43 below.

TABLE 42. Observations on comparative resistance to wilt by Minami and certain non-resistant varieties under the same conditions. (in greenhouse)

Variety	1934			1935			Average of wilt percentages
	Total number of individuals	Wilted individuals at 3 weeks after emergence	Wilt percentages	Total number of individuals	Wilted individuals at 3 weeks after emergence	Wilt percentages	
Minami	240	24	10.00	—	—	—	10.00
Hokkaido-zairaishu	186	177	95.16	254	230	90.55	94.52
London	174	165	94.83	188	169	89.89	92.36
Holland	177	123	69.49	192	144	75.00	72.23
Dutch	177	153	86.44	146	126	86.30	86.37
Belgium	180	150	83.33	249	220	88.35	85.84
Odessa	183	165	90.16	—	—	—	90.16
Pernau	256	224	87.50	192	168	87.50	87.50
France	182	168	92.31	152	148	97.37	94.58
Russia	195	183	93 85	199	184	92.46	93.15
Chokeishu	186	159	85.48	206	198	96.12	90.80
Shinkoku-ama	192	105	54.69	172	144	83 72	69.20
Ichigoshu	183	153	83.61	200	164	82.00	82.80
Indoshu	153	101	66.01	197	158	80.20	73.11

In the first experiment, as shown in Table 42, the susceptibility of these varieties to the wilt was unexceptionally greater than that of Minami variety. That is, under greenhouse conditions the percentages of wilted plants in those varieties ranged from the maximum 94.5 to the minimum 69.2%, while Minami variety showed only 10.00% wilting.

In the second experiment, as shown in Table 43, the relations to the wilt disease of the F_1 plants produced by crossings between each of 13 susceptible varieties and Minami variety were examined in comparison with their resistant and susceptible parents. Taking the mean values of the wilt percentages of Minami variety and each maternal variety respectively as the standard, the F_1 plants of

TABLE 43. Occurrence of the wilt in F_1 generation between each of non-resistant varieties and Minami variety. (1935)

Combination	Total number of plants	Number of wilted plants	Wilt %-tage 3 weeks after emergence	Wilt %-tage of		Average wilt %-tage of parents
				susceptible parent(1)	resistant parent	
Russia × Minami	40	18	45.00	93.15	10.00	51.58
France × Minami	24	10	41.67	94.58	,,	52.29
Pernau × Minami	18	10	55.56	87.50	,,	48.75
Odessa × Minami	32	0	0	90.10	,,	50.08
Belgium × Minami	38	13	34.21	85.84	,,	47.92
Dutch × Minami	24	8	33.33	86.37	,,	48.19
London × Minami	36	18	50.00	92.36	,,	51.18
Holland × Minami	30	14	46.67	72.25	,,	41.13
Chokeishu × Minami	28	16	57.14	90.80	,,	50.40
Shinkoku-ama × Minami	40	14	35.00	69.20	,,	39.60
Ichigoshu × Minami	40	20	50.00	83.80	,,	46.40
Hokkaido zairaishu × Minami	32	20	62.50	94.52	,,	52.26
Indoshu × Minami	38	16	50.00	73.11	,,	41.56

(1) cf. Table 41.

7 combinations (viz., Russia, France, Odessa, Belgium, Dutch, London, and Shinkokuama × Minami) showed more or less higher, while those of 6 combinations (viz., Pernan, Holland, Chokeishu, Ichigoshu, Hokkaidozairaishu, and Indoshu × Minami) showed somewhat lower wilt percentages than the mean value. At any rate, the relations to the wilt disease of these F_1 hybrids were more or less intermediate between their resistant and susceptible parents.

(b) Inheritance of the wilt resistance in F_2 generation.

In order to study the segregation of the wilt resisting character in F_2 lines, the occurrence of the wilt disease in each line of the F_2 generation was examined on sick soil under greenhouse conditions. Soil moisture and soil temperature were kept at 39–41% and 20–23°C. respectively to favor the occurrence of the disease during the experiment.

TABLE 44. Occurrence of the wilt in F_2 plants of every non-resistant variety × Minami variety. (1936)

Combination	Total individuals (A), wilted individuals (B), healthy individuals (C) & wilt %-tage (D)	F_2 lines															Total	Ratio
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Indoshu× Minami	A	13	6	6	15	6	9	8	10	8	10	9	10	6	8	17	141	
	B	1	0	1	5	1	3	1	0	0	0	0	0	0	0	1	13	1
	C	12	6	5	10	5	6	7	10	8	10	9	10	6	8	16	128	10
	D	7.69	0	16.67	33.33	16.67	33.33	12.50	0	0	0	0	0	0	0	5.88	9.22	
Dutch× Minami	A	30	36	30	27	38	28	8	26	28	21	26	29	26	30		383	
	B	16	20	4	13	15	2	2	11	1	3	0	1	6	2		96	1
	C	14	16	26	14	23	26	6	15	27	18	26	28	20	28		287	3
	D	53.33	55.56	13.33	48.15	39.47	7.14	25.00	42.31	3.57	14.29	0	3.45	23.08	6.67		25.07	
Odessa× Minami	A	49	34	44	20	23	27	26	27	24	42	9	42				367	
	B	8	3	4	2	4	7	1	9	0	11	1	6				56	1
	C	41	31	40	18	19	20	25	18	24	31	8	36				311	6
	D	16.33	8.82	9.09	10.00	17.39	25.93	3.81	33.33	0	26.19	11.11	14.29				15.26	
London× Minami	A	22	15	13	16	14	10	19	7	9	5	14	9	16	21	28	218	
	B	11	5	5	6	1	0	0	0	1	0	0	0	0	3	2	34	1
	C	11	10	8	10	13	10	19	7	8	5	14	9	16	18	26	184	6
	D	50.00	33.33	38.46	37.50	7.14	0	0	0	11.11	0	0	0	0	14.29	7.14	15.60	
Russia× Minami	A	5	16	21	17	15	15	10	4	15	6	26	16	17	3	17	203	
	B	1	5	1	2	1	3	6	3	10	1	9	5	1	1	0	49	1
	C	4	11	20	15	14	12	4	1	5	5	17	11	16	2	17	154	4
	D	20.00	31.25	4.76	11.77	6.67	20.00	60.00	75.00	66.67	16.67	34.62	31.25	5.88	33.33	0	24.14	
Holland× Minami	A	8	8	7	8	14	8	10	7	8	5	10	17	8	9	9	136	
	B	0	0	1	0	1	0	0	0	0	0	0	4	0	2	1	9	1
	C	8	8	6	8	13	8	10	7	8	5	10	13	8	7	8	127	4
	D	0	0	14.29	0	7.14	0	0	0	0	0	0	23.53	0	22.22	11.11	6.62	
Pernau× Minami	A	6	10	23	23	19	14	8	7	14	21	18	18	26	14	17	238	
	B	2	2	9	10	2	0	1	0	1	1	2	3	1	1	1	36	1
	C	4	8	14	13	17	14	7	7	13	20	16	15	25	13	16	202	6
	D	33.33	20.00	39.13	43.48	10.53	0	12.50	0	7.14	4.76	11.11	16.67	3.85	7.14	5.88	15.13	

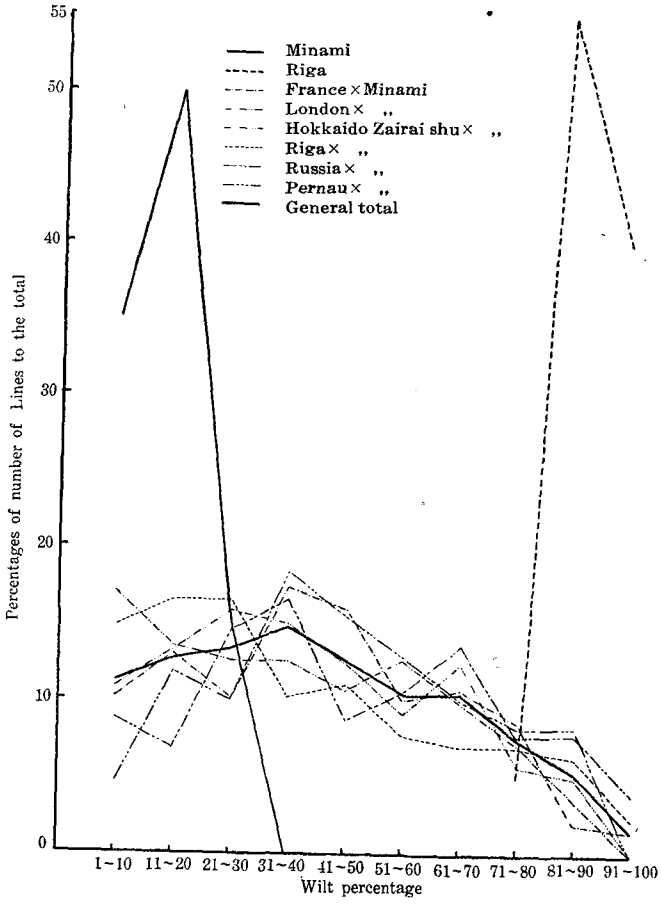
TABLE 44. (*Continued*)

Combination	Total individuals (A), wilted individuals (B), healthy individuals (C) & wilt %-tage (D)	F_2 lines															Total	Ratio
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Belgium × Minami	A	24	25	7	21	28	22	38	18	24	9	35	26	10	30	30	347	
	B	14	4	1	3	11	0	1	0	6	1	15	1	0	1	10	68	1
	C	10	21	6	18	17	22	37	18	18	8	20	25	10	29	20	279	4
	D	58.33	16.00	14.29	14.29	39.29	0	2.63	0	25.00	11.11	42.86	3.85	0	3.33	33.33	19.60	
Chokeishu × Minami	A	20	16	28	17	16	16	8	15	15	22	15	5	6	21	15	235	
	B	3	5	16	1	3	1	3	1	3	2	1	0	0	14	9	62	1
	C	17	11	12	16	13	15	5	14	12	20	14	5	6	7	6	173	3
	D	15.09	31.25	57.14	5.88	18.75	6.25	37.50	6.67	20.00	9.09	6.67	0	0	66.67	60.00	26.38	
Shinkokuama × Minami	A	14	13	15	14	22	50	50	50	20	49						297	
	B	0	0	2	1	0	2	3	20	6	7						41	1
	C	14	13	13	13	22	48	47	30	14	42						256	6
	D	0	0	13.33	7.14	0	4.00	6.00	40.00	30.00	14.29						13.80	
Hokkaidozairaishu × Minami	A	10	19	10	24	13	18	9	16	26	16	13	12	12	8	15	221	
	B	2	8	1	4	1	1	2	1	10	4	7	0	0	0	0	41	1
	C	8	11	9	20	12	17	7	15	16	12	6	12	12	8	15	180	4
	D	20.00	42.11	10.00	16.67	7.69	5.56	22.22	6.25	38.46	25.00	53.85	0	0	0	0	18.55	
Ichigoshu × Minami	A	17	12	7	10	21	12	13	8	13	2	5	9	11	3	9	152	
	B	1	3	2	3	3	0	2	2	3	1	3	4	3	3	2	35	1
	C	16	9	5	7	18	12	11	6	10	1	2	5	8	0	7	117	4
	D	5.88	25.00	28.57	30.00	14.29	0	15.58	25.00	23.08	50.00	60.00	44.44	27.27	100.00	22.22	23.03	
France × Minami	A	10	10	14	15	11	14	10	11	10	13	14	16	10	17	17	172	
	B	4	3	5	6	3	0	1	0	0	0	0	2	1	0	0	25	1
	C	6	7	9	9	8	14	9	11	10	13	14	14	9	17	17	167	7
	D	40.00	30.00	35.72	40.00	27.27	0	10.00	0	0	0	0	12.50	10.00	0	0	13.02	
General total	A																3130	
	B																565	1
	C																2565	5

TABLE 45. Variations of wilt percentage in F_2 hybrids between each of non-resistant varieties and Minami variety in comparison with Minami and Riga varieties.

Combination	Number of lines (A) & its %-tage to total number of lines (B)	1–10%	11–20%	21–30%	31–40%	41–50%	51–60%	61–70%	71–80%	81–90%	91–100%	Total number of lines
Minami	A	7	10	3	0	0	0	0	0	0	0	20
	B	35.00	50.00	15.00	0	0	0	0	0	0	0	
Riga	A	0	0	0	0	0	0	0	1	11	8	20
	B	0	0	0	0	0	0	0	5.00	55.00	40.00	
Fance × Minami	A	14	18	14	24	22	14	15	12	3	2	138
	B	10.14	13.04	10.14	17.39	15.94	10.14	10.87	8.70	2.17	1.45	
London × Minami	A	19	15	14	14	12	14	11	8	4	0	111
	B	17.11	13.51	12.61	12.61	10.81	12.61	9.91	7.21	3.60	0	
Hokkaido zairaishu × Minami	A	13	16	19	18	15	11	15	7	6	0	120
	B	10.83	13.33	15.83	15.00	12.50	9.17	12.50	5.87	5.00	0	
Riga × Minami	A	19	21	21	13	14	10	9	9	8	3	127
	B	14.96	16.54	16.54	10.24	11.02	7.87	7.09	7.09	6.30	2.36	
Russia × Minami	A	9	7	15	17	9	11	14	8	8	4	102
	B	8.82	6.86	14.71	16.67	8.82	10.78	13.73	7.84	7.84	3.92	
Pernau × Minami	A	5	13	11	20	17	14	11	9	9	0	109
	B	4.59	11.93	10.09	18.35	15.60	12.84	10.09	8.26	8.26	0	
Total number of lines of all crossings (C)		79	90	94	106	89	74	75	53	38	9	707
%-tage of C to general total		11.17	12.72	13.30	14.99	12.59	10.47	10.61	7.50	5.38	1.28	

In experiment No. 1, 10–15 F_2 lines each of 13 crossings were examined, and daily observations on the wilting were made through 27 days after emergence. At the end of the experiment, the ratio of total wilted to surviving individuals and the wilt percentage were calculated. The results are given in Table 44.



Text-fig. XXIV. Curves showing the distribution of strains in F_2 according to the wilt percentage.

Experiment No. 2 was carried out to examine the variation of wilt resistance in 6 combinations, 100 F_2 lines, comparing with those of Minami and Riga varieties. The methods of the experiment were quite similar to the previous one, and the occurrence of the wilt

was observed daily until 25 days elapsed from the emergence of the seedlings. All lines examined were classified into 10 classes according to their wilt percentages in decadal divisions; the results of this experiment are summarized in Table 45 and Text Fig. XXIV.

(3) General conclusions drawn from the results of genetical studies of inheritance of the wilt-resistance.

A careful consideration of the results obtained in the present experiments made it clear that the wilt percentages in the F_2 plants vary according to the different crossings of the paternal varieties, and also in some cases to the difference of line in the same parental combination. In some crossings, a majority of the F_2 lines showed comparatively high wilt percentages, while in other cases many of the highly wilt-resistant lines were bred true. It was evident that the wilt resisting character of Minami variety segregated in the F_2 families of several crossings with each of the wilt-susceptible flax varieties, but the mode of segregation was neither simple nor regular according to the difference in lines. As shown in Table 43, the wilted and surviving F_2 plants of every crossing showed variable ratios which are out of the theoretical ratio 3:1. From this fact it was deduced that the inheritance of the wilt-resistant character of Minami variety is controlled by multiple factors.

As shown in Table 45, it is clear that Minami and Riga varieties are quite differently effected by wilting, that is, in Minami variety there is no line which showed higher wilt percentage than 30%, and one half of all lines showed such low wilt percentages as 11–20%; on the other hand, in Riga variety, the wilting of all lines was higher than 71–80%, and in 40% of them the wilt percentage was as high as 91–100%. In regard to the six different crosses of susceptible varieties with Minami variety, F_2 lines showed segregations in various degrees of the wilt resistant character. Especially in crosses of London × Minami and Riga × Minami, most of the F_2 lines showed very high resistance. Also in other cases, resistant lines were generally more numerous than susceptible ones.

Text Fig. XXIV shows the variation curves with respect to the results of Table 45. It is noticeable from the figure that the modes of variations of all F_2 populations lean nearly to that of the resistant parent. Therefore it can be said that in F_2 generation the resistant

lines generally predominate over the susceptible ones. From the above results, it may be concluded that the wilt resistance of Minami variety is partially expressed by F_1 population in crossing with a wilt susceptible variety; and in F_2 population the segregation of the resistaint character occurs in various degrees, but it is noticed that many of the F_2 lines are as highly resistant as the resistant parent. In this case the mode of variation of F_2 populations leans distinctly to that of the resistant parent, and a remarkable inclination to the side of the resistant parent is generally observed in the variation curve. From this fact, it can be said that the wilt resistance of Minami variety is strongly inherited by the descendants in the crosses with susceptible varieties. Moreover, it was recognized that if a large number of F_2 lines were observed, the variation might be represented by a frequency curve, and from this viewpoint the resistance should be explained genetically as a character which is inherited according to multiple factors. Accordingly, although Minami variety is not proved as the best fibre flax it will be invaluable as a resistant parent in the breeding of wilt resistant fibre flax.

XI. Discussion and conclusion

(1) The origin of flax variety "Minami" and its peculiarities.

The wilt disease of flax which occurs from the infection of *Fusarium Lini* BOLLEY, most seriously menaces the crop. It most virulently attacks the host plants at the seedling stage. Therefore, its prevention has been considered as a most important problem from scientific and practical points of view. Numerous authoritative investigations have been carried on precisely studying its nature in detail but several points in the problem of the practical prevention of this disease remain unsolved. Some investigators have carried out studies on certain wilt resistant strains of flax, but no fully satisfactory results have yet been attained, so that in practice this serious disease of flax can be prevented only by a long term crop rotation which is inconvenient. The shortening of this long term crop rotation is requisite for the advancement of the cropping of flax and for the rationalization of agricultural practice. From this stand point it is of the greatest importance to breed some wilt-resistant and superior flax variety.

In 1892, the late Prof. Emer. T. MINAMI started a series of field experiments on successive cropping at the experimental farm of the Faculty of Agriculture of the Hokkaido Imperial University which has been continued till the present time. In this experimental series a plot of flax is comprised. In this field the wilt disease ravages severely, and the ordinary variety of flax plant is almost annihilated year by year. In the 11th year of the course of this experiment it happened that a few individuals of Riga variety survived and showed a high resistance to the wilt disease. Several resistant strains have been bred true among the descendants of those individuals. One of them, numbered M 63–24–4–4–4, showed especially high wilt resistance. Several investigators have paid attention to this wilt resistant flax but many important problems on its characteristics are left unsolved. The present writer studied the morphological and physiological characters and the wilt resistance of this flax strain in detail.

First he confirmed its morphological peculiarities in the size and weight of seed, colour of seed coat, inner structure of seed, characters of seedlings, stomatal constructions and structures of root system in comparison with the mother Riga and other flax varieties, and concluded that it is a distinct variety distinguishable from any other varieties. He named it "Minami variety" in memory of the breeder, the late Dr. T. MINAMI.

Minami variety showed far more vigorous growth than the other 14 flax varieties taken in comparison in greenhouse and in field, and it was highly resistant to the wilt disease beyond comparison with the other varieties. It was clear that Minami variety being quite different in several morphological and physiological characters from its mother variety Riga and any other flax variety cultured ordinarily in Japan, it is an unique and most interesting variety.

(2) The relation of soil moisture to the wilt resistance.

In the present studies the results showed a tendency for the occurrence of the wilt disease in flax to decrease according to an increase of soil moisture. It seemed to be analogous to the results obtained by former investigators in similar studies on wilt diseases of various plants caused by Fusaria. The tendency was similar both in the resistant Minami variety and susceptible Riga

and other varieties, but the actual severity of the wilt occurrence was far greater in susceptible varieties than in Minami variety. The writer should like to interpret the decrease of the wilt occurrence in increasing soil moisture as due to the facts that an ample soil water favors the development of flax seedlings to resist the fungus attack, and further that a sufficient water supply may prevent the wilting caused by shortage of water in plant tissues. On the contrary when the soil moisture was low, the plant would readily be brought to droughty condition and would become wilted. High temperature favoring the development of the pathogene and increasing the transpiration of flax seedling, accelerates the wilting remarkably. The great differences of wilt percentage in Minami variety and susceptible varieties at various degrees of soil moisture revealed that the wilt resistance in Minami variety is not fundamentally influenced by a variation in soil moisture.

(3) The relation of soil temperature to the wilt resistance.

Development of plant diseases caused by soil inhabiting fungi is greatly influenced by soil temperature. For this reason the following two conclusions have been reached: (1) the soil temperature directly influences the development of parasitic fungi: (2) the soil temperature influences the physiological functions or the histological developments of host plants, and consequently changes their resistance or susceptibility to the parasites. Owing to the single or synthetical sequence of these influences occurrence of the disease seems to be accelerated or retarded by a fluctuation of soil temperature.

In the present experiment, the occurrence of the wilt diseased flax seedlings on the "flax sick soil" was markedly influenced by soil temperature, and the vicissitude of the wilt occurrence according to the varying soil temperatures was widely different in the resistant Minami variety and in the susceptible other varieties. At low soil temperature, Minami variety having shown strong resistance to the wilt, absolutely none or a few plants were killed by attack of the disease at temperatures up to 23°C., which is the most favorable one for the growth of flax plant. On the other hand in the susceptible RIGA variety the disease occurred severely and the percentage of the wilted seedlings almost always exceeded 80% at 20–23°C. With the rise of soil temperature, at 26°C. and 28°C. the wilt per-

centages having increased in general, it exceeded 50% sometimes in Minami variety, and the whole number of plants was annihilated frequently in Riga variety. At 30°C. which is the optimum temperature for the development of the causal fungus *Fusarium Lini* BOLLEY, even Minami variety and undoubtedly other varieties could with difficulty survive the fungus attack on the sick soil, and the entire number of seedlings was annihilated as a rule. At the high soil temperatures above 30°C., however, Minami variety seemed to lose its resistance to the wilt, and the wilt percentage of the seedlings was obviously more than that of Riga variety. Severe ravages of the wilt disease at the soil temperature of 30°C. seemed to be interpreted by the almost complete development of the causal fungus at that optimum temperature, but the decline of the wilt resistance in Minami variety at the soil temperatures above 30°C. can not be explained according to the same idea. It should be considered that the high soil temperature unfavorably affected the host plants and weakened their wilt resistance. Because the influences of the high temperature above 30°C. might be unfavorable also for the causal fungus as well as for the flax plant. Neverthless, an outbreak of the wilt disease was more severe in Minami variety than in Riga. As the former is highly resistant and the latter is susceptible to the wilt disease at low soil temperatures, it can be said that the high soil temperature relatively increased the susceptibility of Minami variety and relatively increased the resistance of Riga variety to the wilt disease.

(4) Physiological characteristics of Minami variety in relation the wilt resistance

(a) Types of plasmolysis in relation to the wilt resistance.

In certain cases of the disease resistance in plants it has been known that some physiological characters have great concern in this connection, and physiological peculiarities have frequently been found in resistant plants. Especially, it is most interesting that some protoplasmic characteristics seem to be connected with the disease resistance.

The writer found a possible correlation between the type of plasmolysis and the wilt resistance in flax plant. When inducing plasmolysis in flax cells in sucrose solution or other media, there

were two different types observed, the cramp type and the convex type. In Minami variety the cramp plasmolysis markedly exceeded the convex plasmolysis, on the contrary, in Riga or any other susceptible variety examined, the convex type predominated over the cramp type with no exception. These facts suggested a protoplasmic peculiarity of the resistant Minami variety. Further, the connection between the wilt resistance and the protoplasmic condition in which the cramp plasmolysis predominates over convex one was clearly recognized in similar studies at varying soil temperatures. As already discussed, the wilt resistance in Minami variety was weakened when it grew at the high soil temperatures above 30°C., and at the same time in such seedlings of Minami variety the rate of occurrence of cramp plasmolysis diminished and became less than convex plasmolysis. In Riga variety, however, the rate of occurrence of cramp plasmolysis increased in the seedlings raised at high soil temperatures exceeding that of the convex plasmolysis, and at the same time they were less susceptible to the wilt disease than Minami variety. According to these facts the author concluded that the wilt resistance in flax plants has a close connection with the protoplasmic condition in which the cramp type predominates over convex one in plasmolysis. The soil temperature of the field at the seedling stage of flax in Hokkaido is sufficiently low to reinforce the high resistance of Minami variety to the wilt disease.

(b) Anti-toxicity of flax seedlings.

The antitoxicity of plants to certain inorganic salts has been studied by several investigators, and some of them concluded that there is a correlation between the disease resistance and the antitoxicity to certain ions. Examining the antitoxic reactions of Minami and Riga varieties in the solutions of Na_2CO_3 and $MgSO_4$ the present writer found remarkable differences between them. The antitoxicity of Riga variety to Na_2CO_3 was more conspicuous than that of Minami, while to $MgSO_4$ Minami variety was stronger than Riga. Such a contrast in the antitoxicities of Minami and Riga varieties might be due to the difference of the protoplasmic predisposition of the two.

(c) Sugar content of cells of flax seedlings.

Variation in sugar content of cells has been considered to be sometimes connected with the disease resistance. In the present studies the writer found a slight difference in the sugar contents of the seedlings of resistant Minami and susceptible Riga and other varieties. Especially the amount of invert sugar was only a little, but clearly, smaller in Minami variety than in any other flax variety examined. However, it could not hastily be concluded whether the difference in sugar content has any possible relation to the wilt resistance or not.

(d) Water content of cells of flax seedlings.

It has been generally believed that the water content of plants has a close relation to their resistance or susceptibility to diseases. The writer found a difference in the water contents of young seedlings between Minami and Riga varieties. In the present studies the water content of Minami variety was a little but distinctly larger than that of Riga variety. Although any direct relation of the water content to the wilt resistance could not be demonstrated, it may have some significance in the appearance of the wilt symptom which was favored by dry condition of soil or by water deficiency in the seedlings.

(e) Hydrogen-ion concentration of the ex-pressed sap of flax seedlings.

Several investigators are inclined to attribute great significance to the acidity of cell sap in the considerations of disease resistance in plants. The writer found a slight difference of hydrogen-ion concentration of the expressed sap between Minami and Riga varieties. It was a little higher in the former than in the latter. The difference was too slight to be brought into the consideration of the wilt resistance in the case of the flax varieties.

(f) Freezing point of expressed sap of flax seedings.

As the freezing point of cell sap has direct connection with its osmotic pressure, it has been conceived that a variation in the freezing point of cell sap sometimes has significance in respect to

resistance of a plant to the invasion of fungus hyphae and accordingly to the disease resistance. The writer measured the freezing point of the squeezed-out sap of wilt resistant Minami and susceptible Riga varieties, but there was no definite difference recognized between them.

(5) Inheritance of the wilt resistance.

The peculiarities in morphological and physiological characters and the extremely high wilt resistance of Minami variety having been cleared up, the writer studied the inheritance of the wilt resistance in the crosses of Minami variety and Riga or any of the other susceptible flax varieties. Among the several former investigators of this line, BOLLEY (1912), a pioneer investigator on the control of flax-wilt by means of developing a resistant variety, said about his wilt resistant variety of flax that the resistant character of his variety was maintained by culturing on sick soil, and it declined due to continuous cultivation on clean soil. On the other hand, TISDALE (1917a, b,) said that the wilt resistance in flax is influenced by the environmental factors, and it is a heritable character dominated by multiple factors. In his studies BARKER (1923) held a diverse opinion that the resistance of flax to the wilt would not be essentially changed easily by environmental conditions and that wilt resistance is an inheritable character comparable with any other genetic character, but that the reaction of both resistant and susceptible strains of flax is altered greatly by environmental influences. The difference is merely that between the genotypic and phenotypic phase. BURNHAM (1932) also stated, in his papers on the inheritance of Fusarium wilt resistance in flax, that in the F_3 from the cross of a resistant with a susceptible strain, only a small percentage of the families were as resistant as the resistant parent, most of the families fell into the highly susceptible classes and a few showed intermediate degrees of resistance, but whether these were pure or segregated was not determined. In the crosses between certain resistant strains of different origin, a high percentage of wilt occurred. He concluded that those parental strains may carry different factors for wilt resistance and this may be important in the breeding of new resistant strains.

Experimental and observational evidence of the present studies confirmed that the wilt resistance of Minami variety, however, is

not decreased at all by continuous cultivation on clean soil. After this resistant variety was isolated in the field of the successive cropping experiment over 35 years ago, it has been cultivated on clean soil year after year, but its strong resistance to the wilt is unfailingly remarkable at present. The wilt resistance of Minami variety was found to be diminushed at the high soil temperature above 30°C., but it was sufficiently remarkably and constant at low temperatures below 23°C. which is normal in field at the seedling stage of flax plants in Hokkaido.

In F_1 generation of the crosses of Minami and Riga or other susceptible varieties, the hybrids were as a rule intermediate in respect to wilt resistance, and in the selfed lines in F_2 generation the wilt resistant character segregated and diverse variation of the *wilting* was observed in the F_2 progenies. The segregation ratio in F_2 generation being a little out of the theoretical ratio 3:1, it was considered that the wilt resistance of Minami variety is due to a character or characters dominated by multiple factors. It was proved in the practical field experiments that the wilt resistance of Minami variety is dominantly heritable in the crossings with susceptible varieties, especially with Riga, London, Hokkoido-zairaishu, France and Pernau. In these crossings, almost more than 50% of all F_2 lines showed wilt percentages less than 40%, which were far smaller than those of the susceptible parent. From these facts, Minami variety is to be considered as a hopeful parent in the breeding of wilt-resistant flax.

The suitability of Minami variety as a fibre flax seems to be to rerable but not excellent, but its wilt resistance is extremely strong. As the wilt resistant character of Minami variety has been proved to be dominantly heritable in the crossings with several superior varieties of fibre flax, it ought to be highly valued as a parental variety in the crossings to secure a practically superior and highly wilt resistant fibre flax.

XII. Summary

(1) In the present paper a detailed account of some comparative studies concerning the relation between the wilt resistance of Minami variety and environmental influences, physiological charac-

teristics, and some genetical studies are reported, presenting the excellence of Minami variety for the breeding of flax.

(2) Flax wilt, caused by *Fusarium Lini* BOLLEY, exerts the most destructive injury to flax crop. Because the pathogene is a soil fungus, flax can not be grown successively on the same field. For the prevention of this menace a long-term rotation cropping of more than 6–7 years is generally employed in flax culture. But for the advancement of intensive agriculture such a long rotation system is obviously an unreasonable method, and it is a very important problem that by the physiological, pathological and genetical investigations of wilt resistance, resistant and excellent flax strains should be bred for the profitable cultivation of this migratory crop.

(3) A wilt resistant strain was selected and bred from some resistant individuals of Riga variety in the experiment of successive cropping of flax which was directed and carried out by the late Prof. MINAMI at the experimental farm of the Faculty of Agriculture, Hokkaido Imperial University. The writer proposes to recognize this strain as a variety and named this wilt resistant variety "Minami" in memory of the breeder.

(4) By many investigators it has been proved experimentally that disease resistance has close relation to the variation of the environmental condition. The writer, having much interest in this point, worked with special attention through his experiments. He carried out his experiments under artificial control of the environmental conditions, especially the soil temperature and the soil moisture, and examined the influence of their variation on the resistance. Moreover he studied on some physiological characters and the inheritance of the wilt resistance under controlled environmental conditions.

(5) For the comparative experiments on wilt resistance sick soil was used. This sick soil was obtained from a sick field where a successive cropping experiment with flax had been carried out. The results showed severe occurrence of the wilt without any artificial inoculation. To control the temperature and the moisture of the soil, a soil temperature tank and LIVINGSTON's auto-irrigator were used. With these appliances the soil conditions were controlled quite arbitrarily and the experiment were carried out exactly.

(6) In comparison with Riga and other susceptible varieties, Minami variety showed noticeable differences not only in morpholo-

gical characters of seeds and seedlings, but also in the resistance to the wilt. Minami variety show very vigorous growth and strong wilt resistance in comparison with others but it did not always have a higher fibre percentage than other varieties.

(7) According to the results of the experiments carried out under controlled soil moisture, both Minami and Riga varieties showed higher wilt percentage in a low soil moisture than in a high; but in any degree of soil moisture the wilt percentage of Minami variety was much lower than that of Riga variety.

(8) It is well known that wilt resistance and susceptibility are greatly affected by soil temperatures. For Riga variety the optimum soil temperature for the occurrence of wilt seemed to be 26–30°C and even at 20–23°C it showed about 90%, while in high soil temperature above the optimum the wilt percentage decreased greatly. On the contrary, in the case of the resistant variety Minami, the optimum soil temperature for the occurrence of wilt seemed to be 30–33°C. and at 20–23°C. the wilt percentage was very low, while at 26°C. about 90% of all plants were wilted. At the high temperature beyond the optimum, the decreasing of the wilt percentage was not so remarkable as that of Riga variety. Some distinct variation of the wilt percentage in the two varieties was shown as a result of the influence of the soil temperature.

(9) The above mentioned fact cannot be explained only by the variation of the physiological conditions of the pathogene due to the influence of the environmental conditions, but rather it might be considered that the variation of the physiological conditions in the host plants due to the influence of the environmental conditions is the more important causal factor.

(10) From the result of the present experiments it is known that in order to keep the wilt resistance sufficient, the Minami variety ought to be cultured at a soil temperature below 23°C. In Hokkaido, the average soil temperature during the seedling stage of flax is generally lower than 23°C. Thus the soil temperature of the spring season in Hokkaido is a quite suitable condition to aid the resistance of the Minami variety. This is a hopeful characteristic encouraging the belief that Minami variety should play an important role in flax breeding in Hokkaido.

(11) In the comparative study of the cell protoplasm in the root and in the hypocotyl of the seedling, a great difference of

plasmolysis was observed in Minami and Riga varieties. By the comparative observation on the form of plasmolysis, the majority of cases in Minami variety appeared as cramp plasmolysis while in RIGA variety convex plasmolysis was observed to be most frequent. Furthermore the same relations were observed in comparing Minami with many other non-resistant varieties.

(12) Some conclusions are reached about the percentage of the form of plasmolysis, whether cramp or convex type according to the soil temperature, and the existence of a certain positive correlation between the increase of cramp plasmolysis and the wilt percentage.

(13) In the examination of the physiological characteristics of Minami and Riga varieties, differences in the antitoxicity to solutions of $MgSO_4$ and Na_2CO_3 were compared. Quite a distinct difference in the anti-toxicity to each solution was found. To the solution of $MgSO_4$, the anti-toxicity of Riga was stronger than that of Minami, but to Na_2CO_3 solution the opposite relation was detected. This fact might be considered to have some relation to the difference of physiological characters in the two varieties.

(14) The results of the comparison of sugar content and water content in seedlings and the hydrogen-ion concentration or the osmotic pressure of plant juice showed scarcely any difference in relation to the difference of wilt resistance in Minami and Riga varieties.

(15) By genetical experiments on the wilt resistance of Minami variety, it was recognized that in the crossing of Minami × Riga or its reciprocal, the resistant character of the Minami variety was inherited dominantly by F_1 generation, but in crossings of other susceptible varieties × Minami variety, generally the wilt resistance of Minami variety appeared intermediately in F_1 generation; while in F_2 generations of every case the resistance segregated in various degrees, and as a whole, the majority of all lines expressed a remarkably high wilt resistance. From these results it is concluded that the wilt resistance of Minami variety is inherited according to multiple factors, and it is believed that cross breeding using Minami variety as one parent, shows very hopeful possibilities to obtain a wilt resistant and excellent flax strain.

(16) On account of the essential factor of the wilt resistance in Minami variety, the results of the physiological studies in the

present investigation suggest that the character is a functional peculiarity taking its rise in the character of the protoplasm; therefore as above mentioned, this character appeared in close relation with environmental conditions. Accordingly, from the practical standpoint it is of fundamental importance that scrupulous attention be paid to the environmental conditions in order to display sufficiently the wilt resistance of the Minami variety.

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PLATE I

Explanation of Plate I

Fig. 1. Experimental apparatus including soil temperature tanks and Livingston's auto irrigators for growing the experimental plants (side view).

Fig. 2. Ditto, (front view).

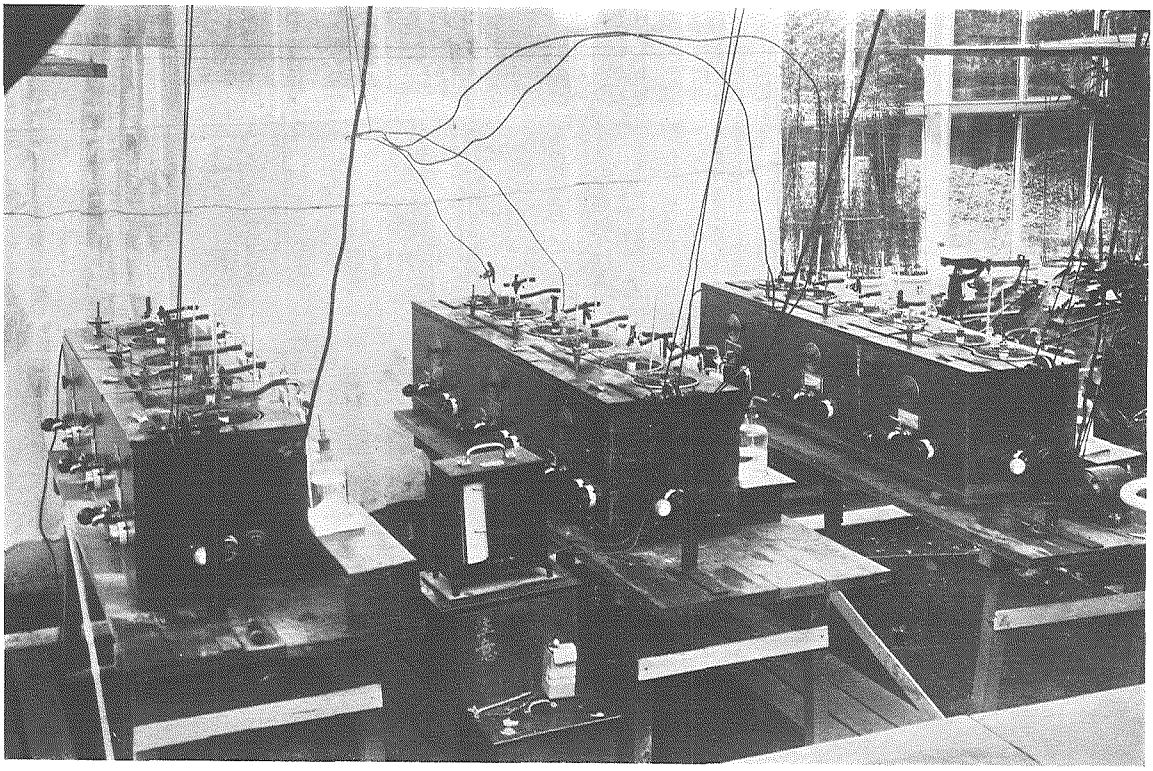

Fig. 1.

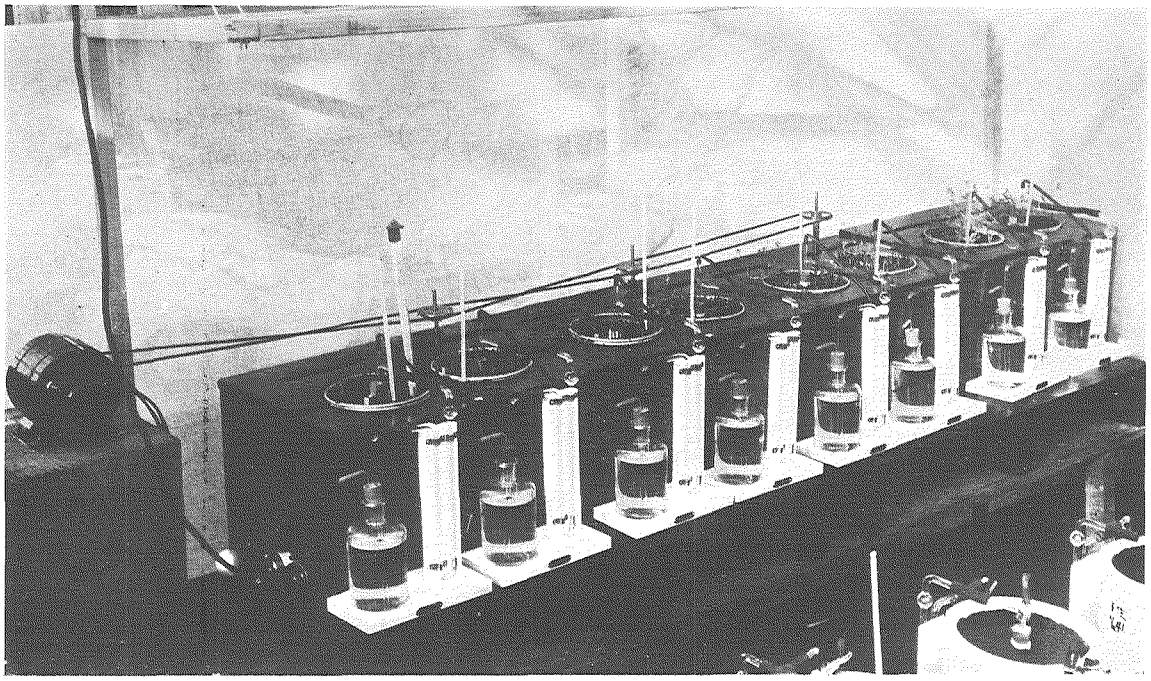

Fig. 2.

PLATE II

Explanation of Plate II

Fig. 3 & 4. Graphs showing the fluctuation of the regulated soil temperature through the entire course of Exp. No. 6 in Section VIII (1–11 denote in order plots of 10°, 16°, 20°, 23°, 26°, 30°, 33°, 35°, 38°, 40° and 45°C. in soil temperature.)

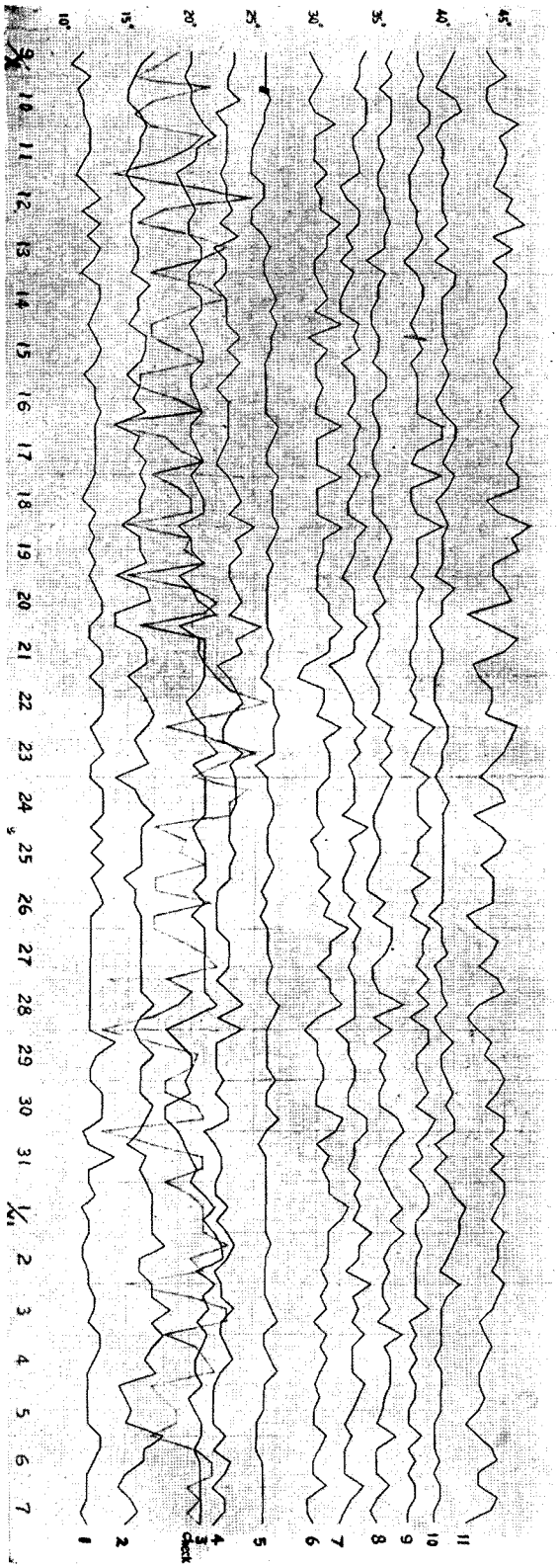

Fig. 3.

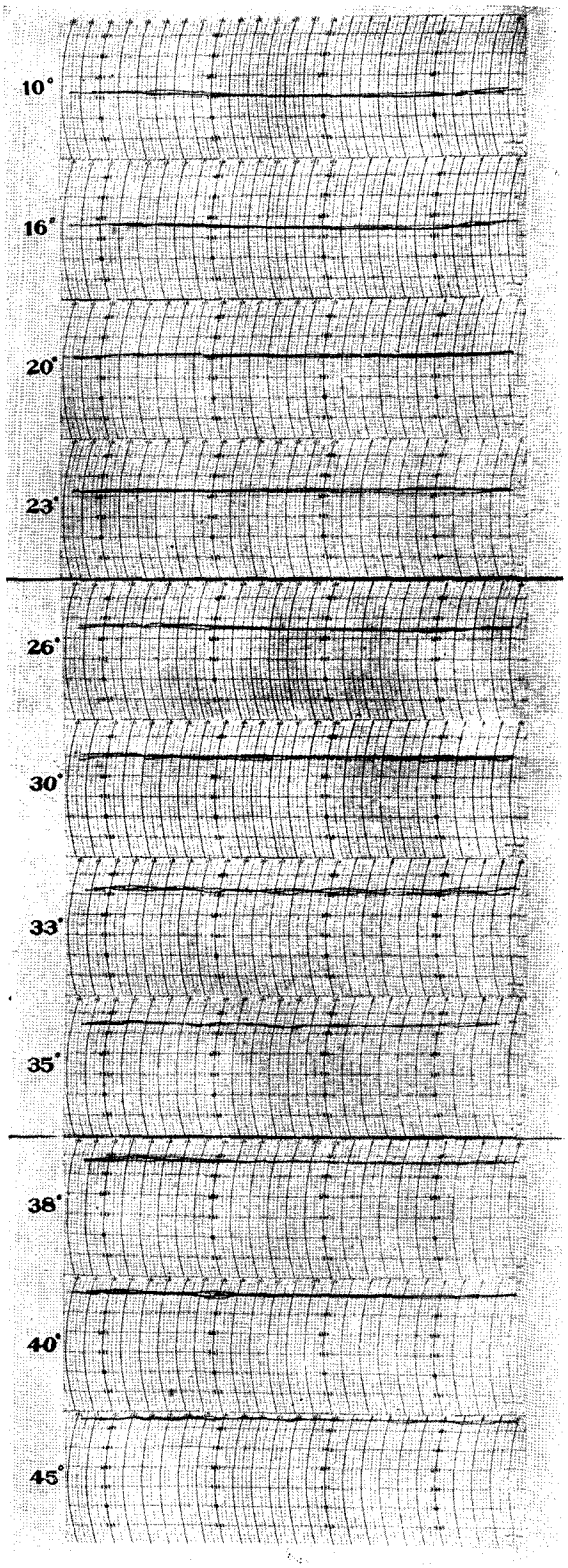

Fig. 4.

PLATE III

Explanation of Plate III

Fig. 5 & 6. Showing the contrast of the wilt occurrences in Minami and Riga varieties 35 days after emergence on sick soil in a glass house. (Fig. 5 shows Minami var. and fig. 6 shows Riga var.)

Fig. 7. Comparison of seedlings of Minami and Riga varieties (M showing Minami variety and R showing Riga variety).

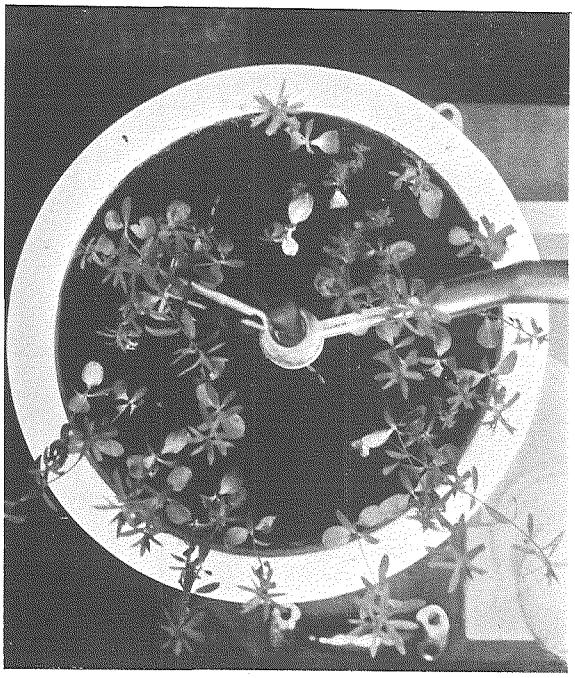

Fig. 5.

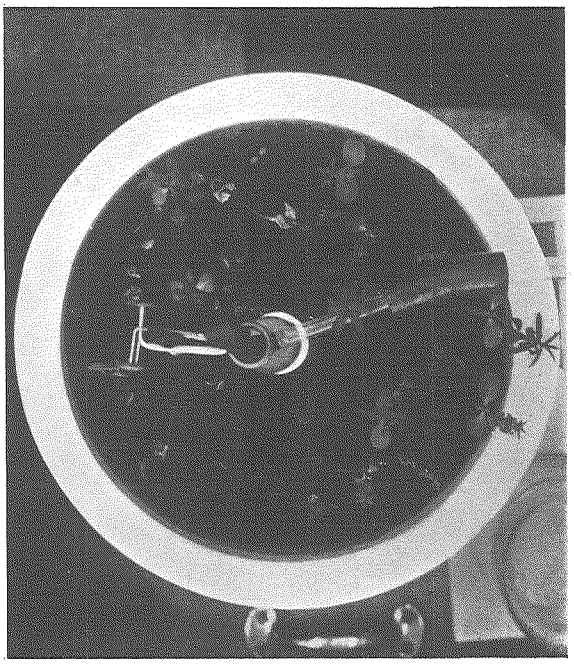

Fig. 6.

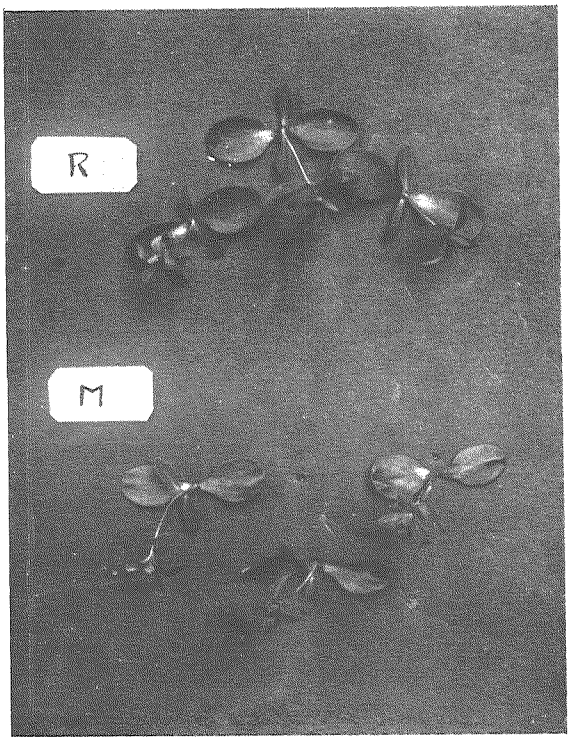

Fig. 7.

PLATE IV

Explanation of Plate IV

Figs. 8 & 9. Comparison of the growth of Minami and other susceptible varieties in a greenhouse.

1 : Minami (left) and Chokeishu (right),

2 : Minami (left) and France (right),

3 : Minami (left) and Belgium (right),

4 : Minami (left) and London (right),

5 : Minami (left) and Shinkoku-ama (right),

6 : Minami (left) and Riga (right),

7 : Minami (left) and Hokkaido-zairaishu (right),

8 : Minami (left) and Russia (right).

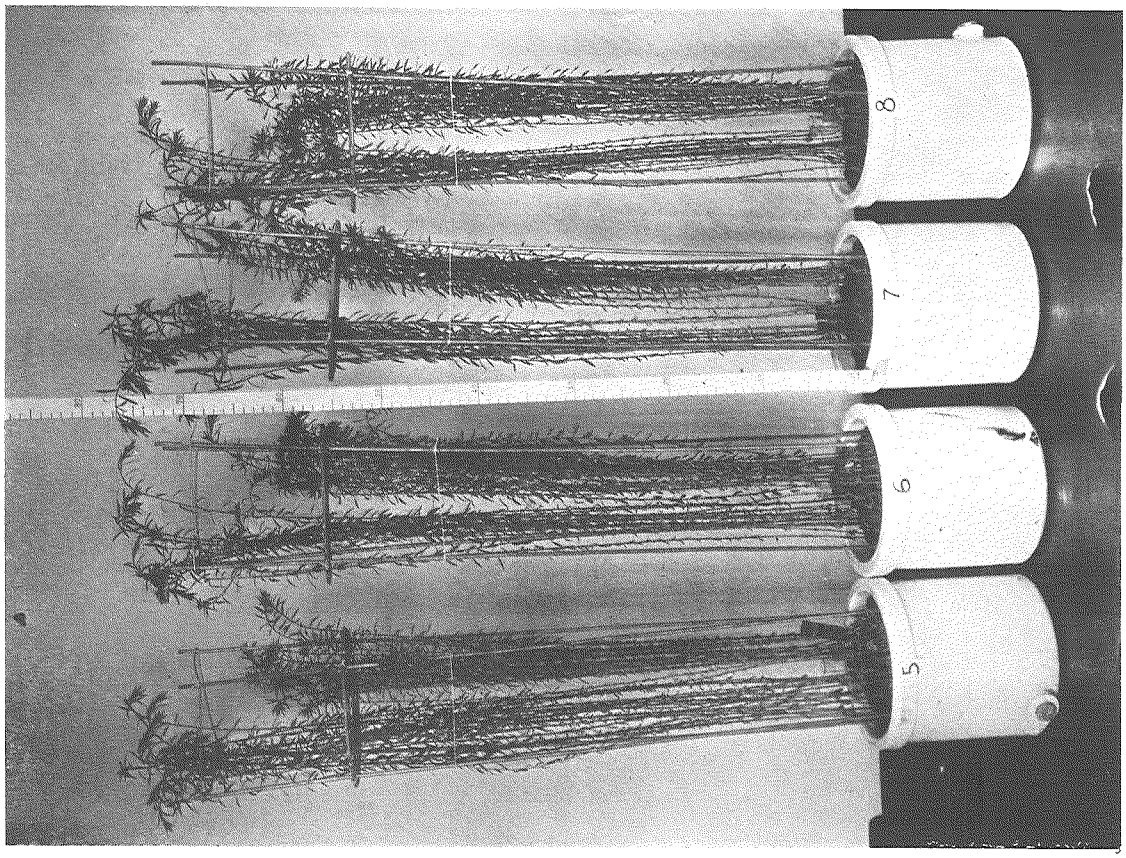

Fig. 9.

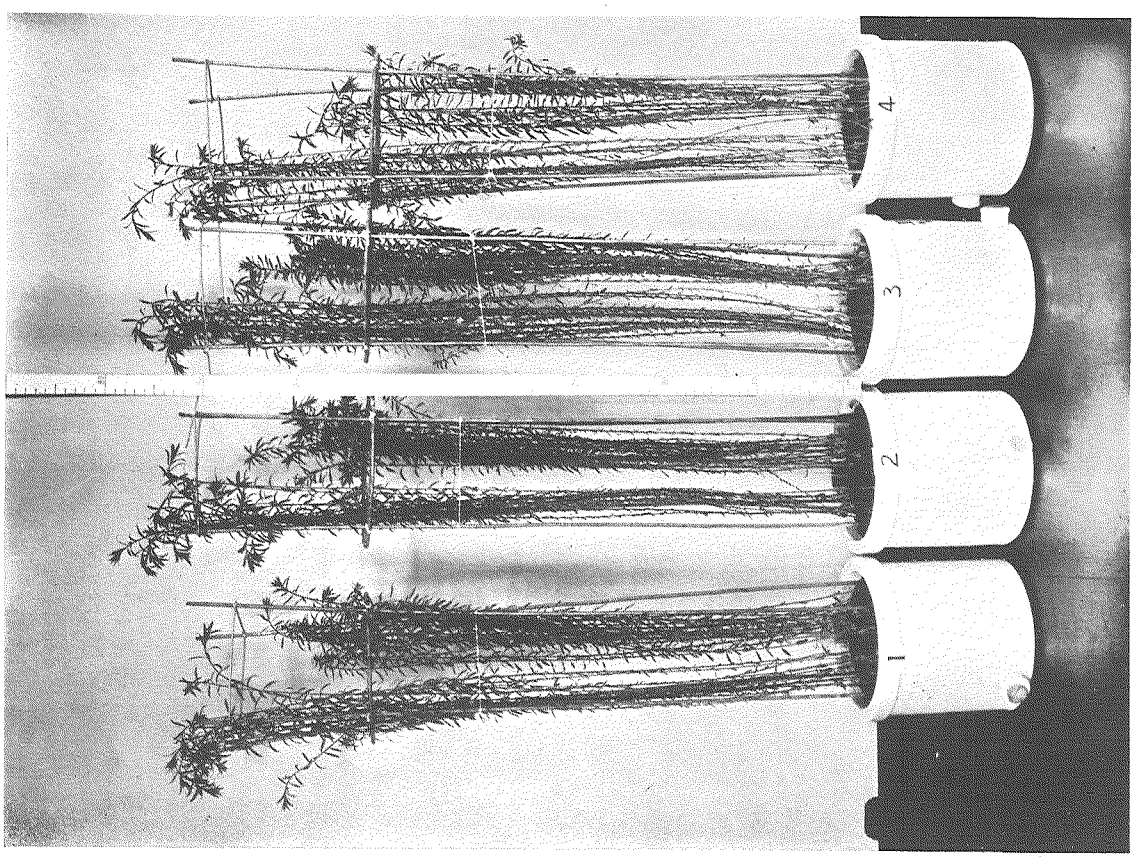

Fig. 8.

PLATE V

Explanation of Plate V

Figs. 10 & 11. Comparison of the growth of Minami and other varieties in natura temperature.

1 : Minami (left) and Chokeishu (right),

2 : Minami (left) and France (right),

3 : Minami (left) and Belgium (right),

4 : Minami (left) and London (right),

5 : Minami (left) and Shinkoku-ama (right),

6 : Minami (left) and Riga (right),

7 : Minami (left) and Hokkaido-zairaishu (right),

8 : Minami (left) and Russia (right).

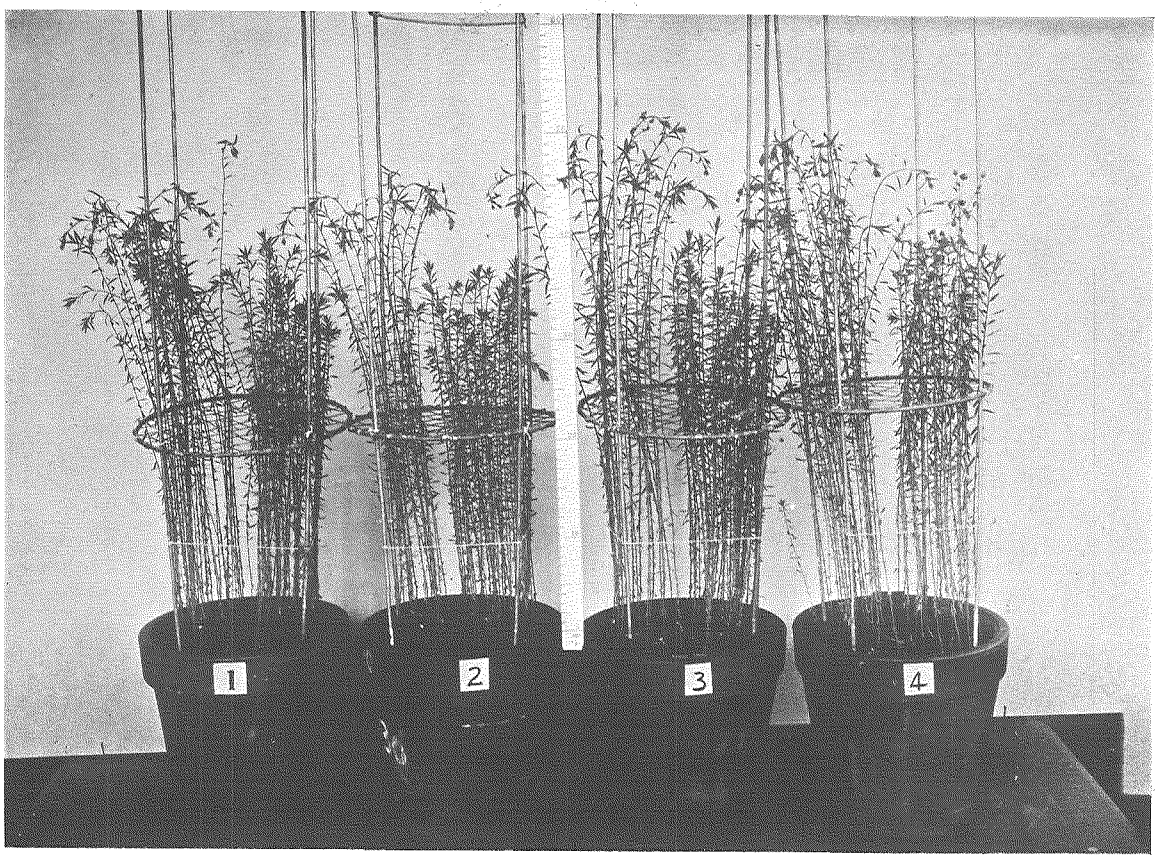

Fig. 10.

Fig. 11.

PLATE VI

Explanation of Plate VI

Showing the occurrence of the wilting in comparison of Minami and Riga varieties on the soil varied in moistures.

Fig. 12. Minami variety at 23.45% soil moisture.

Fig. 13. Riga variety at 23.45% soil moisture.

Fig. 14. Minami variety at 25.46% soil moisture.

Fig. 15. Riga variety at 25.46% soil moisture.

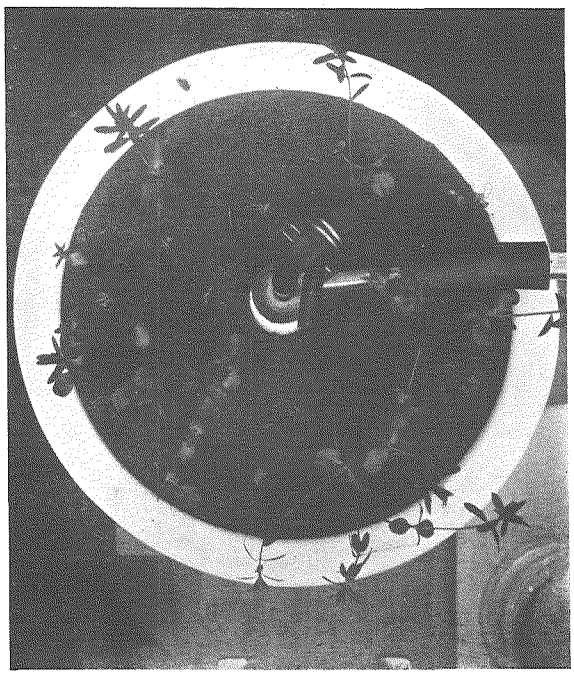

Fig. 12.

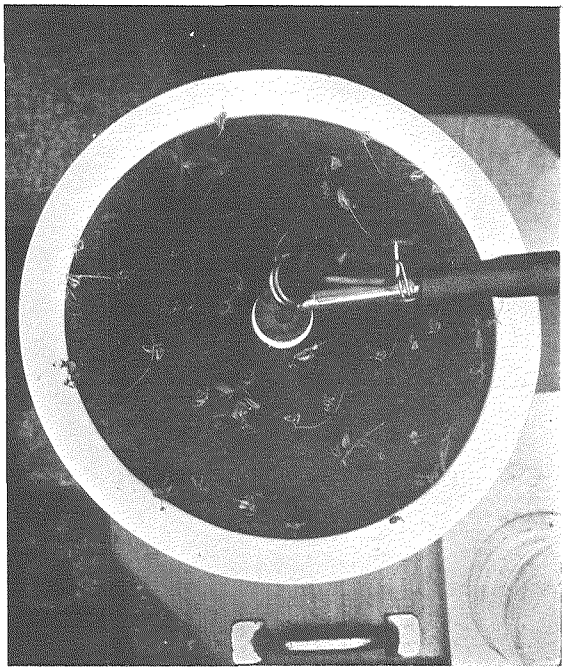

Fig. 13.

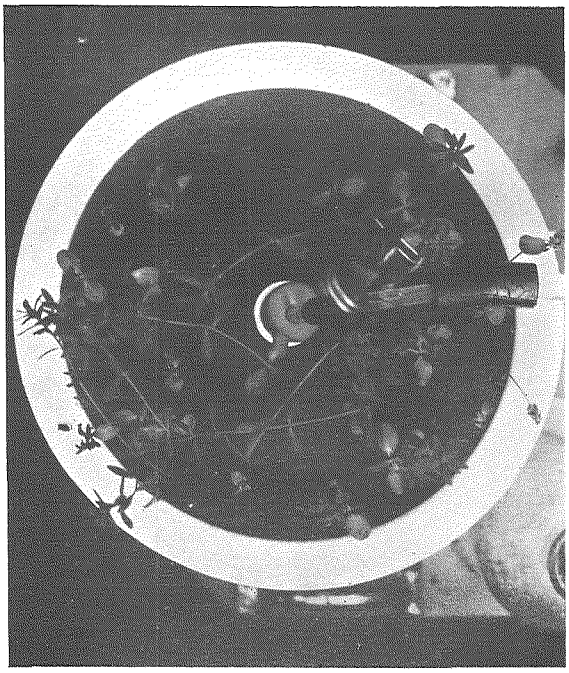

Fig. 14.

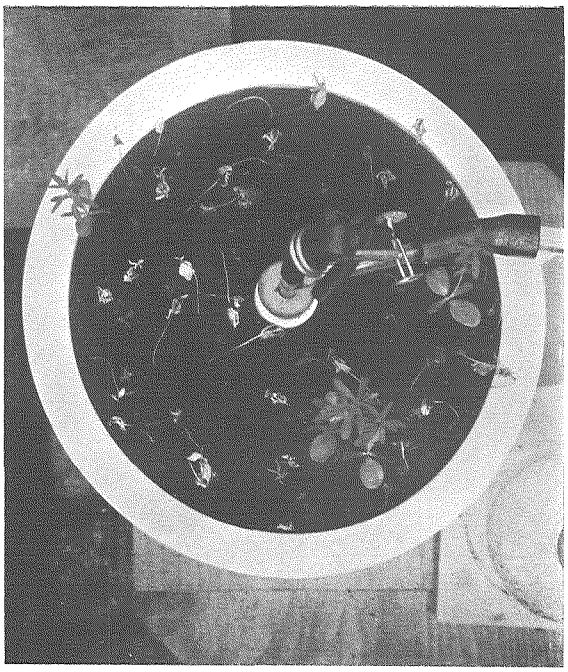

Fig. 15.

PLATE VII

Explanation of Plate VII

Showing the occurrence of the wilting in comparison of Minami and Riga varieties on the soil varied in moisture.

Fig. 16. Minami variety at about 31% soil moisture.

Fig. 17. Riga variety at about 31% soil moisture.

Fig. 18. Minami variety at about 38% soil moisture.

Fig. 19. Riga variety at about 38% soil moisture.

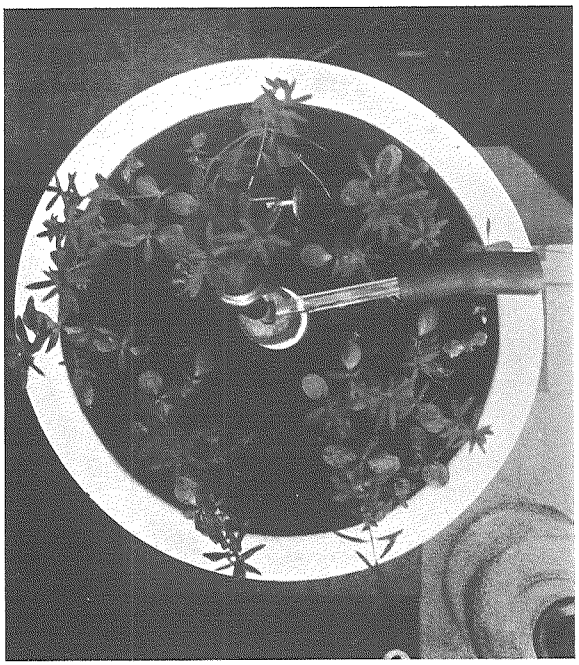

Fig. 16.

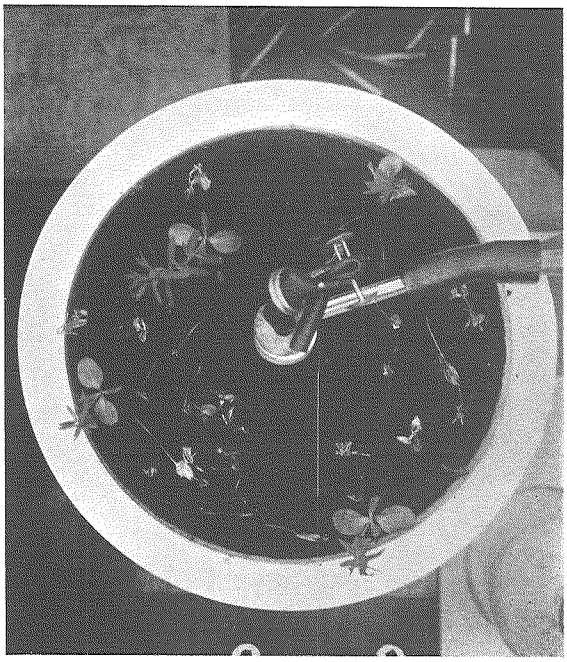

Fig. 17.

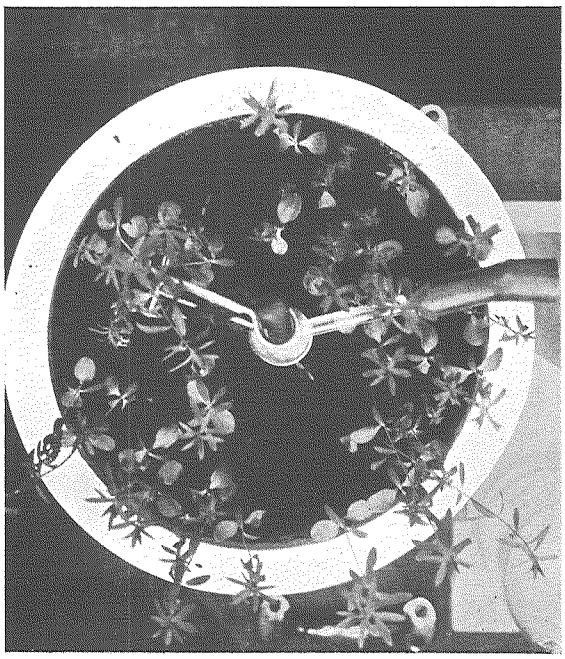

Fig. 18.

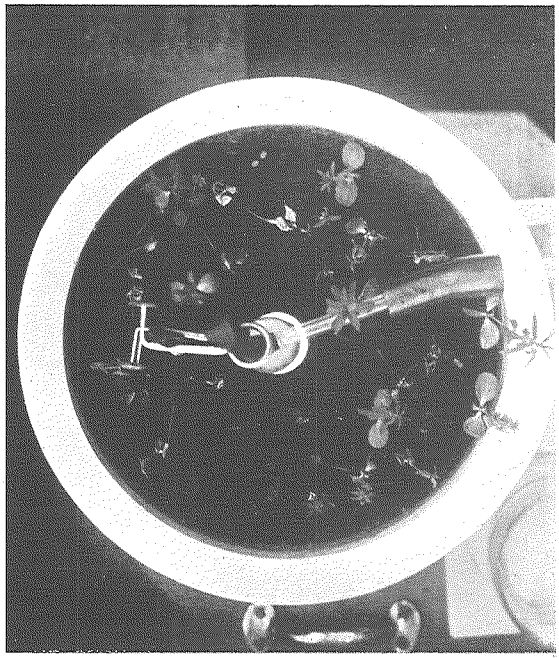

Fig. 19.

PLATE VIII

Explanation of Plate VIII

Showing the vicissitude of the wilt occurrence at varying soil temperatures in comparison of Minami and Riga varieties after 15 days from emergence.

Fig. 20. Minami (left) and Riga (right) varieties at 10°C. soil temperature.

Fig. 21. Minami (left) and Riga (right) varieties at 16°C. soil temperature.

Fig. 22. Minami (left) and Riga (right) varieties at 20°C. soil temperature.

Fig. 23. Minami (left) and Riga (right) varieties at 23°C. soil temperature.

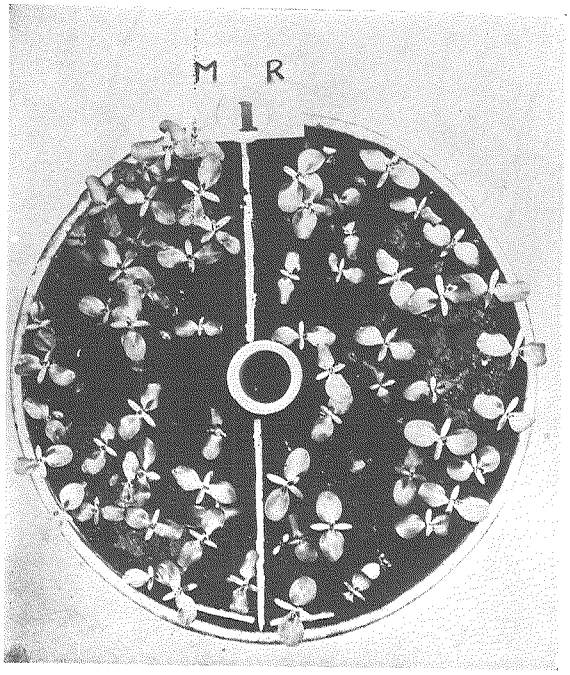

Fig. 20.

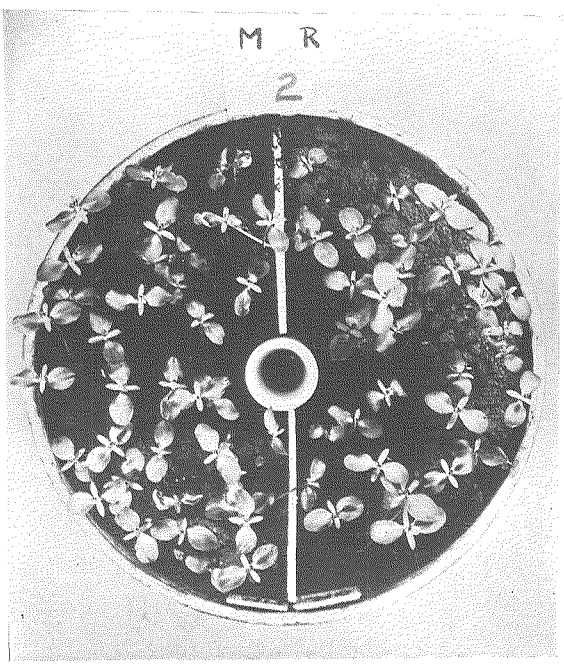

Fig. 21.

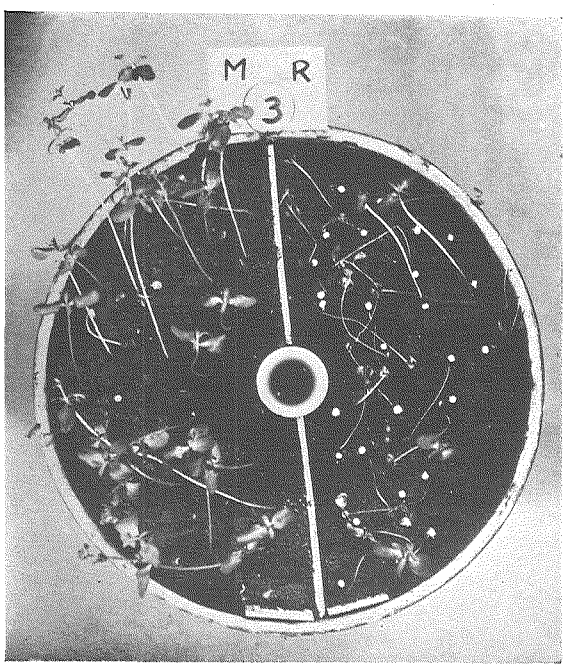

Fig. 22.

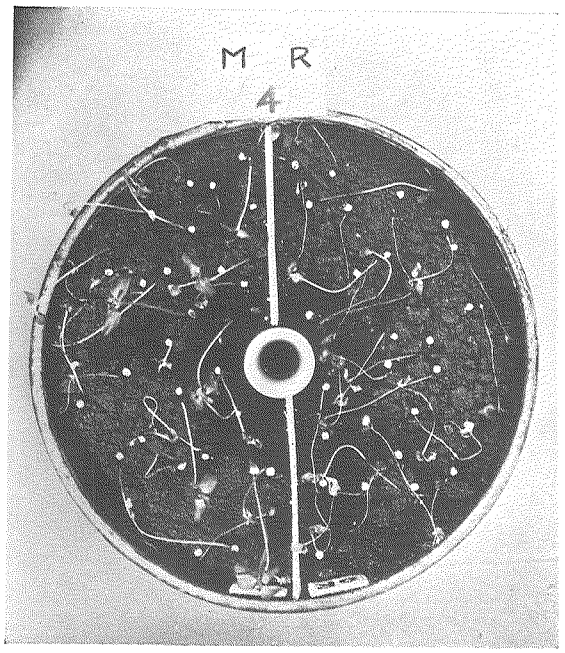

Fig. 23.

PLATE IX

Explanation of Plate IX

Showing the vicissitude of the wilt occurrence at varying soil temperatures in comparison of Minami and Riga varieties after 15 days from emergence.

Fig. 24. Minami (left) and Riga (right) varieties at 26°C. soil temperature.

Fig. 25. Minami (left) and Riga (right) varieties at 30°C. soil temperature.

Fig. 26. Minami (left) and Riga (right) varieties at 33°C. soil temperature.

Fig. 27. Minami (left) and Riga (right) varieties at 35°C. soil temperature.

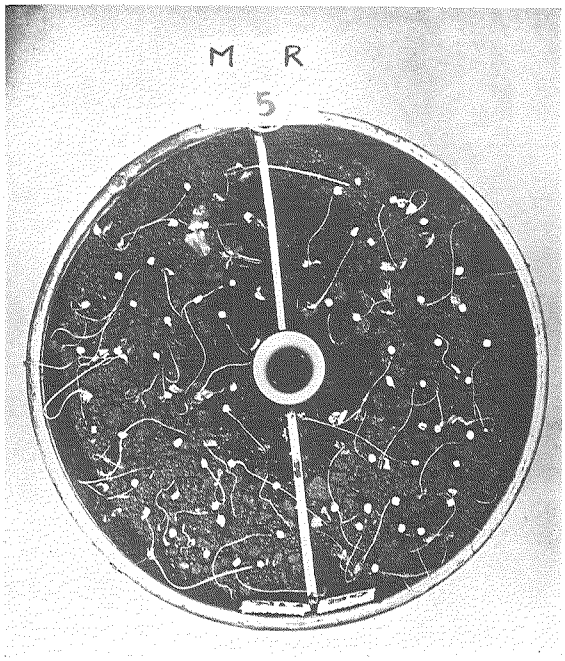

Fig. 24.

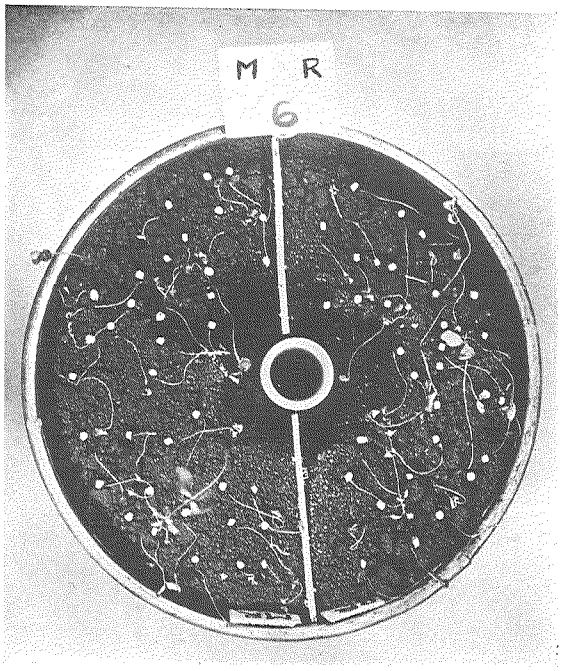

Fig. 25.

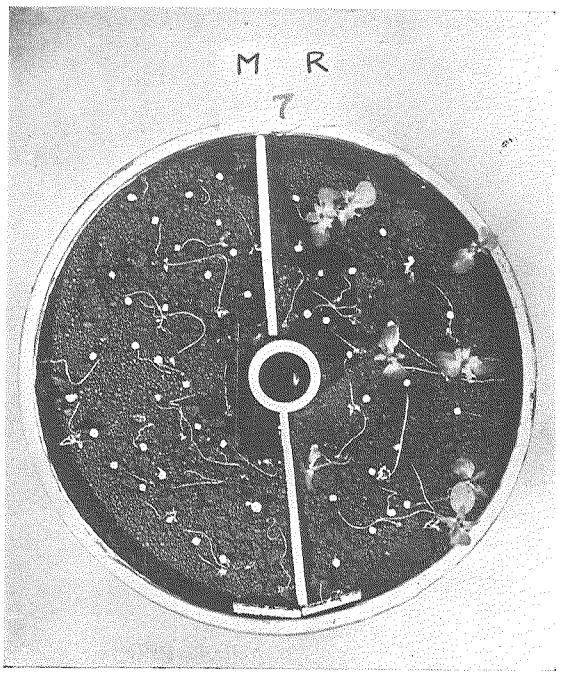

Fig. 26.

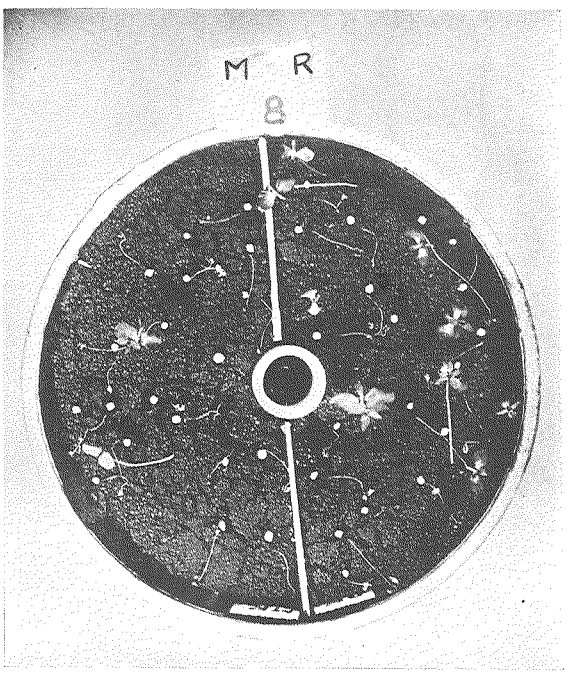

Fig. 27.

PLATE X

Explanation of Plate X

Fig. 28. Minami (left) and Riga (right) varieties at 38°C. soil temperature.

Fig. 29. Minami (left) and Riga (right) varieties at 40°C. soil temperature.

Fig. 30. Minami (left) and Riga (right) varieties at 45°C. soil temperature.

Fig. 31. Minami (left) and Riga (right) varieties in check plot.

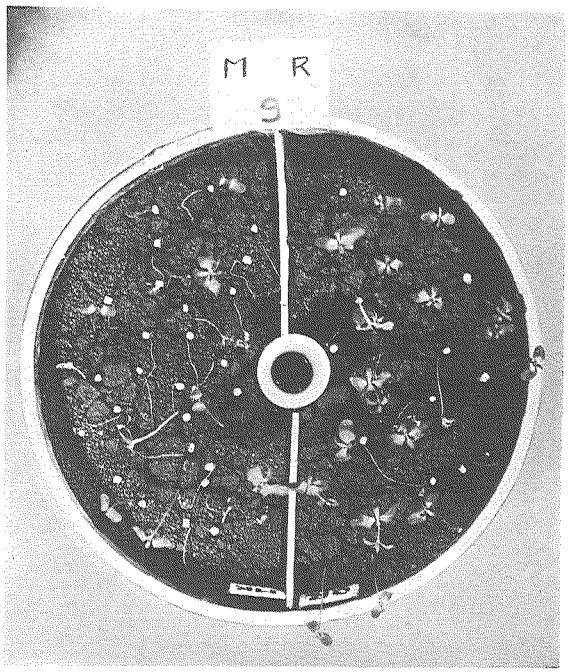

Fig. 28.

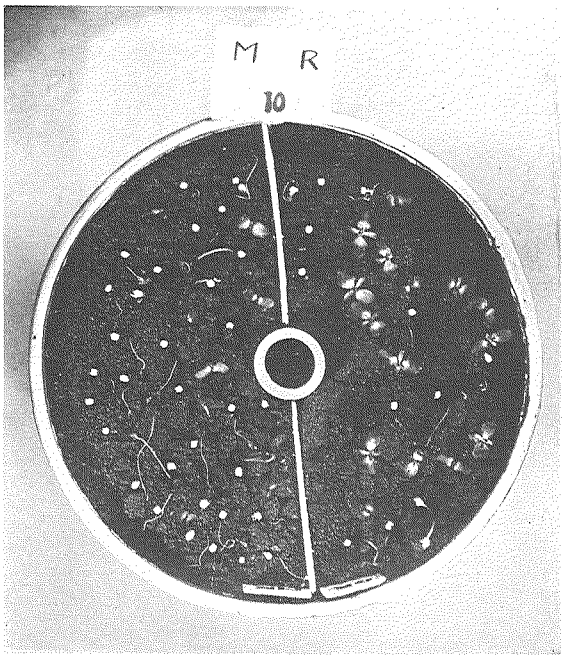

Fig. 29.

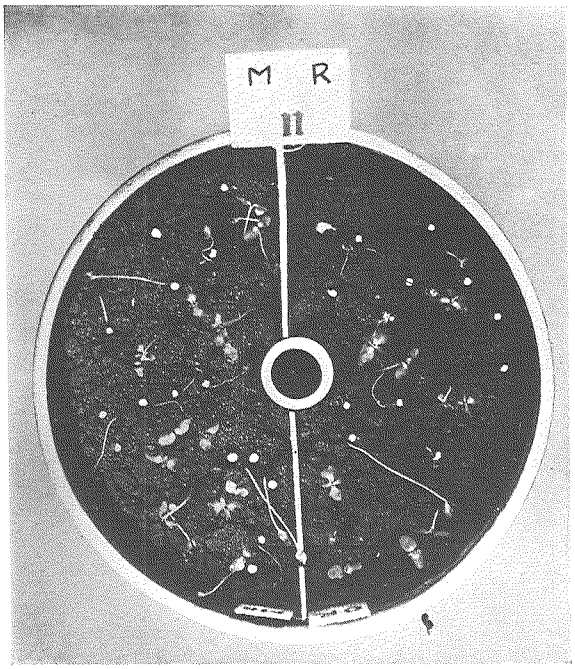

Fig. 30.

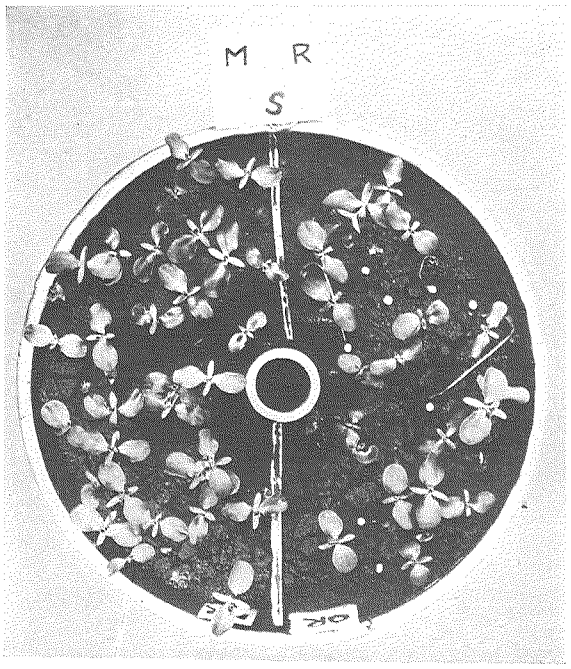

Fig. 31.

PLATE XI

Explanation of Plate XI

Figs. 32 & 33. Microphotographs of cramp plasmolysis induced by 4 mol sucrose solution in epidermal cells of hypocotyl of Minami variety.

Fig. 34. Microphotograph of cramp plasmolysis induced by 0.4 mol sucrose solution in subepidermal tissue of hypocotyl of Minami variety.

Fig. 35. Microphotograph of convex plasmolysis induced by 4 mol sucrose solution in epidermal cells of hypocotyl of Riga variety.

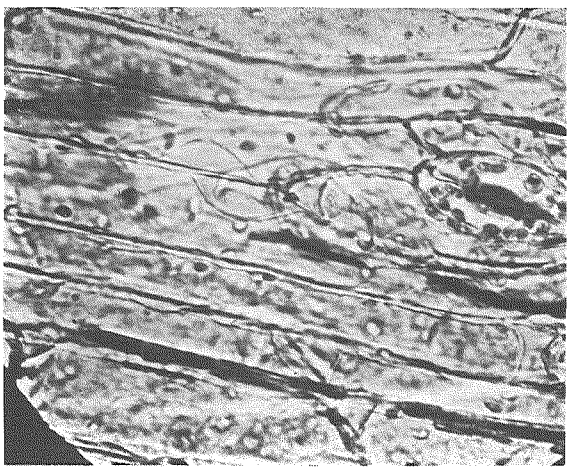

Fig. 32.

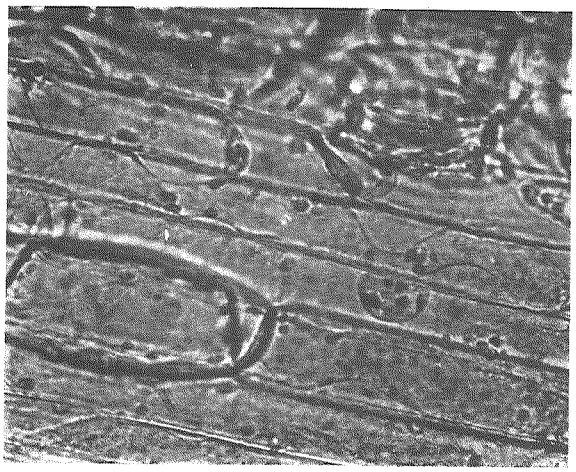

Fig. 33.

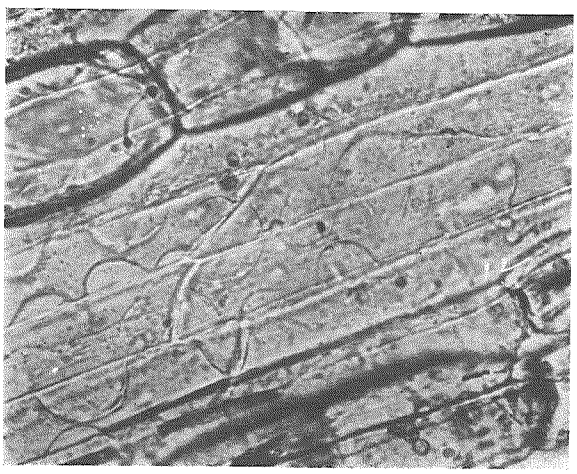

Fig. 34.

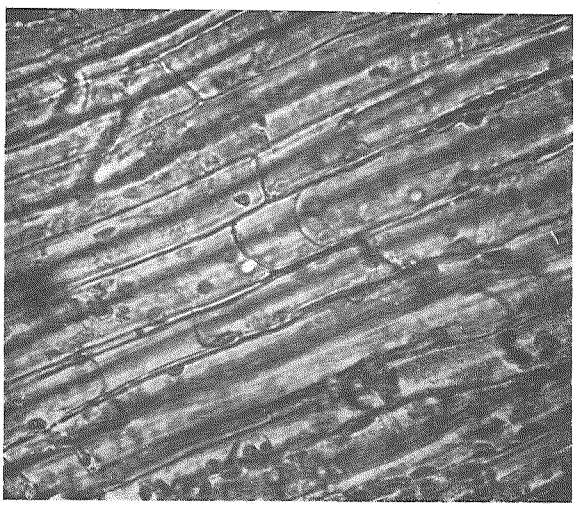

Fig. 35.

PLATE XII

Explanation of Plate XII

Fig. 36. Showing anti-toxicity of the seedlings of Minami variety to $MgSO_4$ solution (photographed 15 days after treatment).

Fig. 37. Showing anti-toxicity of the seedlings of Riga variety to $MgSO_4$ solution (photographed 15 days after treatment).

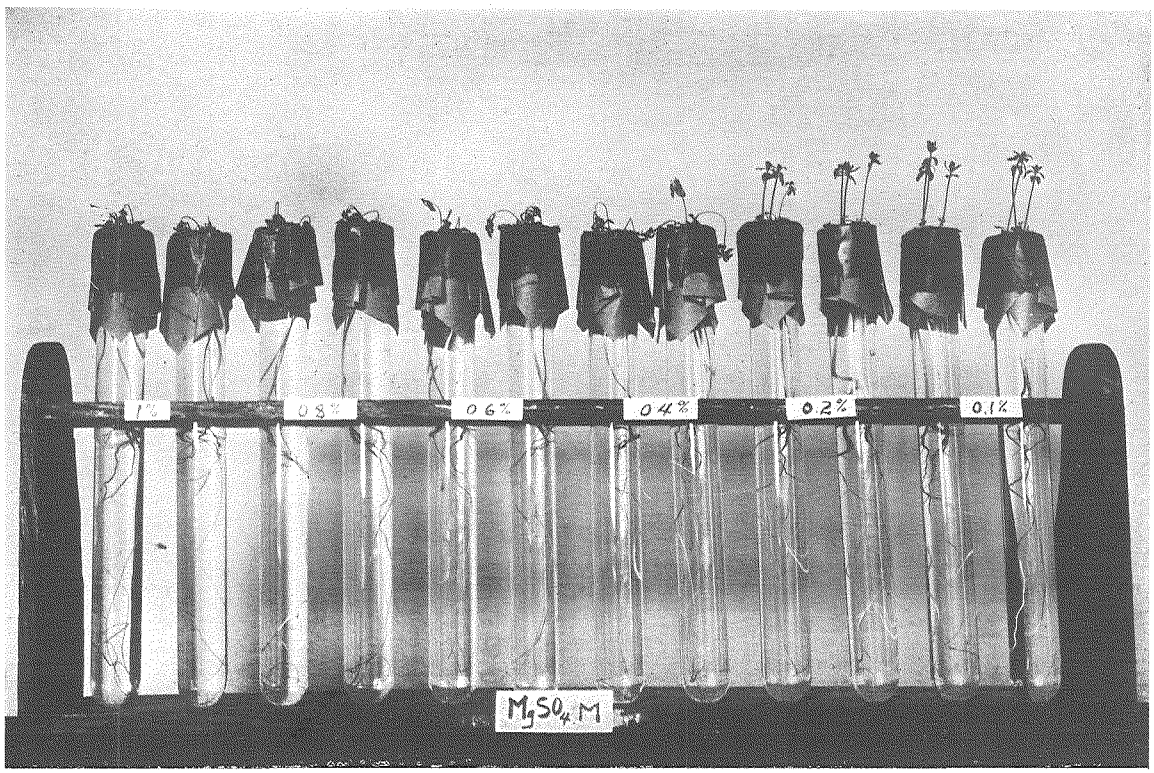

Fig. 36.

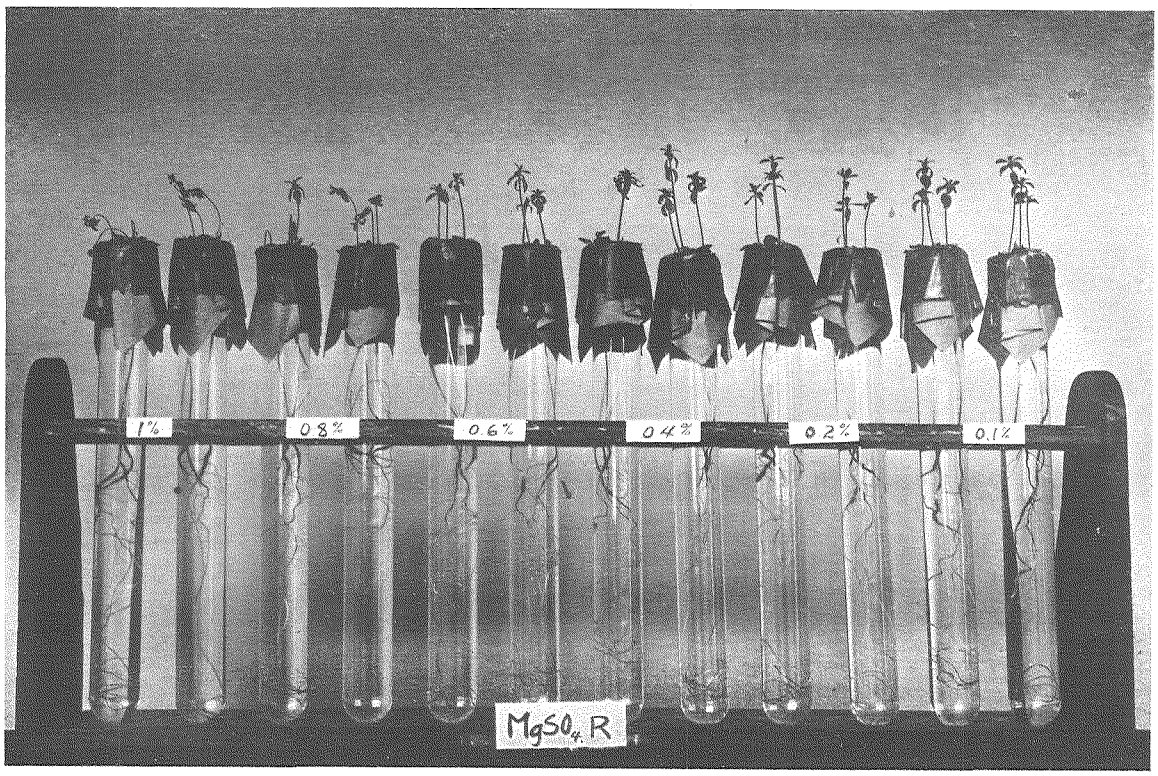

Fig. 37.

PLATE XIII

Explanation of Plate XIII

Fig. 38. Showing anti-toxicity of the seedlings of Minami variety to Na_2CO_3 solution (photographed 14 days after treatment).

Fig. 39. Showing anti-toxicity of the seedlings of Riga variety to Na_2CO_3 solution (photographed 14 days after treatment).

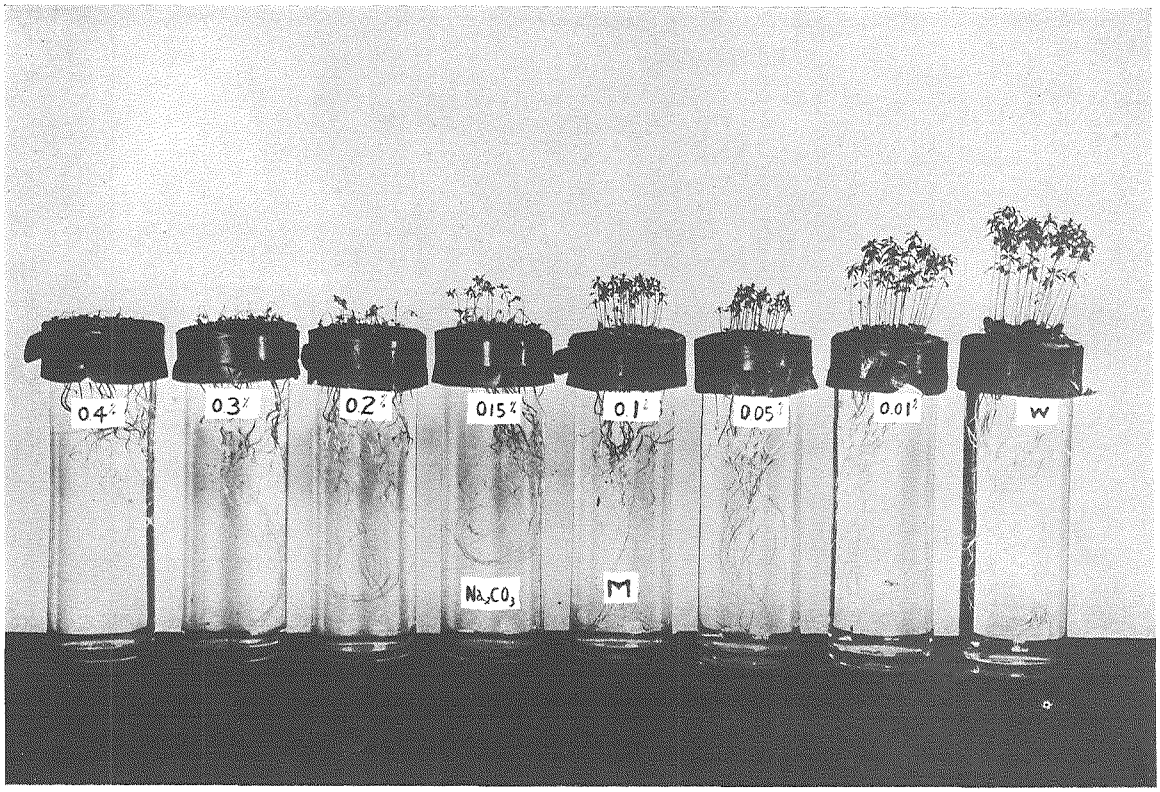
0.4%
0.3%
0.2%
0.15%
0.1%
0.05%
0.01%
W
Na_2CO_3
M

Fig. 38.

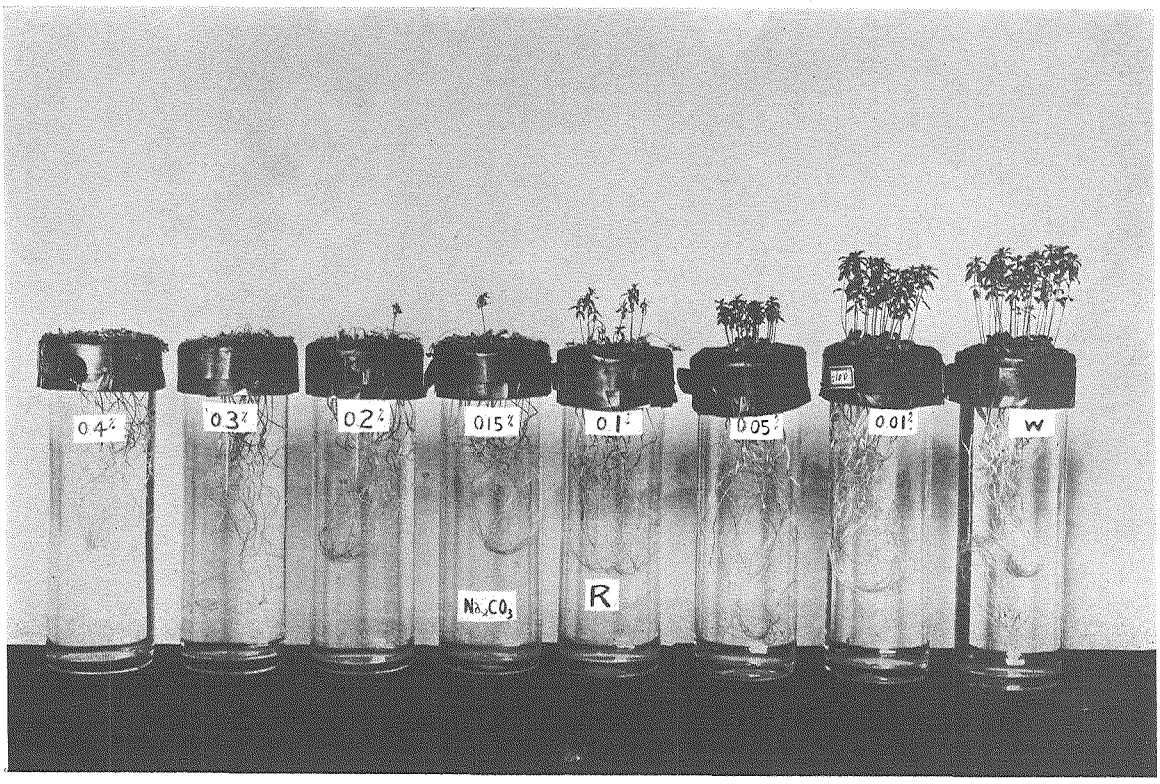
0.4%
0.3%
0.2%
0.15%
0.1%
0.05%
0.01%
W
Na_2CO_3
R

Fig. 39.