

INFLUENCE OF TEMPERATURE ON SYMPTOM EXPRESSION  
OF CERTAIN VARIETIES AND SELECTIONS OF  
WHEAT INOCULATED WITH WHEAT  
STREAK-MOSAIC VIRUS

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1962

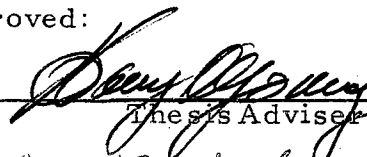
Submitted to the Faculty of the Graduate School of  
the Oklahoma State University  
in partial fulfillment of the requirements  
for the degree of  
MASTER OF SCIENCE  
August, 1965

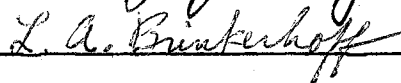
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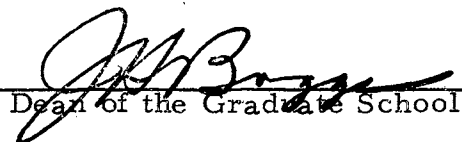
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## ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to his major adviser, Dr. H. C. Young, Jr., without whose help and understanding this investigation would have been impossible, and to other members of my committee, Dr. L. A. Brinkerhoff and Dr. F. B. Struble. I am grateful to Mr. R. C. Bellingham for his aid and helpful suggestions.

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## CHAPTER I

### INTRODUCTION

The most common and most recognizable symptom of infection with the wheat streak-mosaic virus in wheat is the occurrence of light green or yellow streaks in the leaves parallel to the longitudinal axis. During the early part of the infection period, the streaks are usually small, thin and not very prominent. As the infection develops and the leaves become older the streaks widen and turn a deeper yellow color. Often the entire leaf eventually turns yellow. Older leaves with systemic symptoms may sometimes become rolled sideways, at times so tightly that they cannot be unrolled without leaf damage. This symptom resembles that caused by the wheat curl mite, Aceria tulipae Keifer, which is the vector of the wheat streak-mosaic virus. Stunting is also often a prominent symptom in susceptible varieties of wheat.

Virus multiplication and movement, like most biological processes, have been shown to be temperature dependent. Changes in temperature may, therefore, produce changes in the plant reaction and symptom expression. Although wheat varieties differ somewhat in the degree to which they express wheat streak-mosaic disease symptoms, tolerance and resistance have been difficult to find. In the field most commercially grown varieties of hard red winter wheat are completely susceptible and are damaged extensively in certain years and in certain



areas by this disease. Yields in affected areas may be reduced 90 to 100 percent. However, a few varieties and selections have been found to be somewhat tolerant; that is, they will produce a satisfactory yield of grain although exhibiting complete susceptibility to at least the leaf mosaic symptoms of the disease. Such tolerance is rather nebulous and perhaps genetically complex. Development of commercially acceptable hard red winter wheat varieties containing this tolerance may be difficult to accomplish.

A much higher degree of resistance has been found in selections from the intergeneric cross Triticum sp x Agropyron elongatum P. Beauv. Recent evidence indicates that perhaps the resistance expressed by certain of these selections may be genetically more simple than the tolerance characteristic, and therefore, more usable in a breeding program.

The present investigation was undertaken to determine:

(1) the influence of air temperature on the development of the wheat streak-mosaic disease in wheat as measured by the incubation period and the severity of symptom expression; and (2) the influence of temperature upon the expression of symptoms in wheat lines having tolerance or resistance in the field.

## CHAPTER II

### LITERATURE REVIEW

Bawden (1) generalized that with many virus diseases an increase in temperature tends to shorten the incubation period, both with local lesions and systemic types of symptoms. These effects of temperature vary, however, with the host, the virus, or even with strains of a given virus. In many cases the most severe symptom expression is limited to a rather narrow range of temperatures. A definite relationship has been found between the decrease in the severity of symptoms at temperatures above or below the optimum, and a decrease in the virus content of the affected plant. Thus, according to Bawden (1), the effect of temperature is felt not only on virus multiplication, but possibly reflects a disturbance of the balance between the rate at which it multiplies and is inactivated by the host mechanism. The degree of severity of symptom expression seems, more often than not, to be correlated with the amount of virus in the plant; although no generalization can be made.

McKinney (6), working with the wheat streak-mosaic disease in controlled chambers at temperatures from 60° F to 73° F, reported that the warmer temperatures tended to shorten the time from inoculation to the expression of mosaic symptoms. The shortest time he observed was four days, but he regarded the reduction

in incubation time to be of little consequence with this virus disease.

Sill and Fellows (13) studied the degree of symptom expression of wheat streak-mosaic in wheat and found it to be dependent upon temperature. They used five wheat varieties: the hard red spring wheat varieties Lee, Marquis Rival and Webster, and the soft red winter variety Michigan Amer. They concluded from their study that the incubation period increased as the temperature decreased, averaging five days at 82° F, seven days at 68° F and 15 days at 60° F. At an air temperature of 60° F and a soil temperature of 46° F, the incubation period averaged 23 days. Severe symptoms appeared readily at 82° F but at the lower temperatures severe symptom expression required a relatively longer time. Stunting of plants was slight or absent at the lower temperatures, while at the higher temperatures reduction in plant height ranged from 16 to 20 percent.

The age of the plant, as well as temperature, may play a very important part in the infection process with the wheat streak-mosaic virus in wheat. Hansing and co-workers (5) found that when young plants were inoculated more severe symptoms developed than when plants were inoculated at a later stage. Slykhuis (15) had similar results. He reported that plants inoculated at 1 - 2-leaf stages were more severely stunted than those inoculated at successively later stages. On the other hand, Sill (11) reported that when wheat plants were inoculated at the 2-leaf stage, only 16 percent became infected and the incubation period was from seven to ten days. When he inoculated at the 3-leaf stage, 100 percent of the plants became infected, and the incubation period was only seven to eight days.

These results were confirmed by Sill and Fellows (13). Brakke (3), in his experiments with wheat streak-mosaic in wheat, inoculated the plants at the 2-leaf stage, but Bellingham<sup>1</sup> preferred the 3-leaf stage for inoculation with this virus.

Numerous wheat varieties and selections have been tested for tolerance or resistance to the wheat streak-mosaic virus, both in the greenhouse and the field. McKinney (7) inoculated 59 varieties or selections of wheat in the greenhouse at a temperature of approximately 60 to 65° F and found no appreciable amount of resistance. Sill (12) reported that some varieties of wheat had an appreciable amount of tolerance to this disease in the field. Bellingham et. al. (2) found that the tolerance of varieties such as Bison, Kiowa, Webster, Concho, Stafford and Blue Jacket varied with the environment, the time of inoculation, and other factors.

Later, McKinney and Sando (8) worked with the reaction to the wheat streak-mosaic virus in the genera, Triticum, Agropyron, Secale, and in certain intergeneric hybrids. They found that systemic symptoms failed to appear in some Agropyron species. Only a local lesion type of symptom was observed. They also found a Triticum sp x Agropyron elongatum hybrid to be resistant to this virus.

Fellows and Schmidt (4), and Schmidt et. al. (10) reported that several of the Triticum x Agropyron hybrids developed by Sando

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<sup>1</sup>Bellingham, R. C. 1965. Direct Communication. Crop Research Division, Agricultural Research Service, United States Department of Agriculture, Stillwater, Oklahoma.

had some resistance to this disease. Swarup et. al. (14) studied some of these same selections and reported that the plants which were resistant or showed only local lesions tended to be slender, tall and grass-like with long narrow spikes and kernels. The more wheat-like plants developed systemic infection or local lesions, which later became systemic. They examined these selections cytologically and found the resistant grass-like plants to have chromosome numbers much in excess of 21 pairs, while those that were more susceptible and more wheat-like had chromosome complements nearer 21 pairs. They concluded that resistance or local lesion reaction was dependent upon many genes carried on the Agropyron complement of chromosomes in the hybrid. Sebesta and Bellingham (9) reported a selection of a hybrid made by Sando and later designated selection "P3-19" by McKinney (from a Triticum x Agropyron cross) to have resistance to this virus. Further analysis led them to conclude that the resistance was carried on an extra pair of chromosomes.

CHAPTER III  
MATERIALS AND METHODS

Initially, seven varieties or selections of wheat were used to study the effects of temperature on the incubation period and on the severity of symptom expression of the wheat streak-mosaic virus in the greenhouse. These varieties were: Gage C. I. 13532, Ponca C. I. 12128, Comanche C. I. 12673, and a selection of the cross Marquillo x Oro 2x Pawnee C. I. 12851, which are considered susceptible in the field; Concho C. I. 12517 and a selection of the cross Concho 2x Timstein x Pawnee<sup>2</sup> Stw 59R2419-3, which are considered tolerant in the field<sup>2/</sup>; and a selection designated P3-19 by McKinney from the cross Triticum sp x Agropyron elongatum 2x Arlando x Triticum timopheevi 3x Hope x Baart 4x Nebred, which was made by Sando and considered to be resistant by Sebesta and Bellingham (9). Later experiments in growth chambers with more limited space were restricted to the varieties Gage, Concho, the Cch x Tst-Pn<sup>2</sup> selection and the P3-19 selection. Seed of these varieties and selections were obtained from Mr. R. C. Bellingham, Crop Research Division, United States Department of Agriculture, Department of Botany and Plant Pathology, Oklahoma State University, Stillwater, Oklahoma.

Ten "Ceresan M" treated seeds of a single variety were

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<sup>2/</sup> Bellingham, R. C. and H. C. Young, Jr. 1965. Unpublished data. Crop Research Division, Agricultural Research Service, U. S. Department of Agriculture and Oklahoma Agricultural Experiment Station, Stillwater, Oklahoma.

planted around the margin of a five inch pot. Ten pots of each variety or selection were planted (approximately 100 plants) for each temperature used.

Each pot was treated with 60 m.gms. of "Systox" to insure that the plants would remain free of wheat curl mites, and periodically each pot was fertilized with a dilute solution (10 g/1,000 ml) of "Hyponex." Prior to inoculation, all the plants were grown in the same greenhouse where the temperature averaged 21° C but ranged from 18° C to 32° C. Plants were inoculated at the time the fourth leaf was beginning to emerge.

The first two experiments were carried out in greenhouse rooms modified by the addition of refrigeration so that the temperatures could, for the most part, be controlled below the ambient, outside air temperature. In the first study, started in mid-November, an attempt was made to use three temperatures: 16° C, 21° C and 27° C. These temperatures could be held with only minor variations except during the hottest part of the day. At that time the temperature would rise to a maximum of approximately 31° C and return to the desired temperature over an eight to 12 hour period in two rooms (those set at 16° C and 27° C) and to 25° C over a nine hour period in the room set at 21° C. Consequently, the average temperatures, computed by totaling the reading each two hours and dividing by the number of readings, were as follows: for the room set at 16° C, the average was 19° C, with the range of 16° C to 31° C; for the room set at 21° C, the average was 22° C, with a range of 21° C to 25° C; and for the room set at 27° C, the average was 27.4° C, with a range of 27° C to 31° C. The second experiment was started

in mid-March. No attempt was made to obtain the lowest temperature and only two rooms were used. One was set at 21° C and the other at 27° C. Again, the temperature rose over an eight to 10-hour period during the daylight hours to a maximum of 32° C. The average temperatures during the course of the study computed in the manner mentioned above were: the room set at 21° C averaged 24° C, with a range of 21° C to 32° C; and the room set at 27° C averaged 29° C, with a range of 27° C to 32° C. Supplemental fluorescent lighting (1,000 ft. candles) was used, and in the first experiment was set to give a photoperiod of 12 hours.

The third experiment was carried out in growth chambers. Four "Compact" type chambers were used; two manufactured by the Sherer-Gillett Company (Model Number CEL 37-14) and two manufactured by the Percival Refrigeration Company (Model PCG-78). These chambers were maintained at four temperatures: 24° C, 29° C, 35° C continuously, and a diurnal cycle of 32° C daylight and 21° C darkness. The plant bed in each chamber was set so that the plants were exposed to 3,000 to 3,500 ft. candles of light with a 12-hour photoperiod. Four wheat varieties (Gage, Concho, Cch x Tst-Pn<sup>2</sup>, and selection P3-19) were used. For each variety five seeds were planted in each of 20 five-inch pots. Three pots of each variety were then inoculated and placed at each temperature, and two pots of each variety were used as checks at each temperature.

The yellow strain of the wheat streak-mosaic virus (Marmorata virgatum McK. var. typicum McKinney), designated the "Salina strain," was used. Leaves taken from infected plants of the variety Blue Jacket C. I. 12502, obtained from Mr. R. C. Bellingham,



were used for the initial virus source. Each time inoculum was required, an increase of the virus was made on the variety Blue Jacket.

Approximately 40 g. of fresh infected leaves of Blue Jacket were cut into small pieces with sissors, mixed with 360 ml. of water, and ground in a Waring blender for five minutes at 14,000 r.p.m. The extract was poured off and another 40 g. of freshly cut leaves were ground in the same manner. The residue was discarded and the two extracts were mixed together. Two g. of carborundum (600 grit) and 3 g. of Celite (Johns Manville) were added to each 100 ml. of the extract.

The resulting suspension was sprayed on the plants to be inoculated with a De Vilbiss spray gun (type AG F fluid tip) at a pressure of 60 pounds per square inch. Approximately 15 ml. of the extract suspension were used to inoculate each plant. Immediately after inoculation, the pots were transferred to their respective controlled temperatures.

Plants were observed for symptom expression daily until the first symptoms appeared, then intermittently for 30 days or until each experiment was completed. Symptom expression was classified into three major categories: mild (m), moderate (M), and severe (S). Symptoms were classified as mild if only a few light green short streaks were found in the leaf blade. When symptoms had advanced to the point that the streaks were almost uniformly scattered over the leaf and were beginning to show evident yellow color, they were classified as moderate. Symptoms were classified as severe when the streaks were bright yellow and beginning to coalesce. It was,

of course, sometimes difficult to make a decision on symptom classification, since these classes graded into each other. Usually, the first symptoms to appear were mild and the severity increased with time. Sometimes, however, mild symptoms appeared but did not progress further, and occasionally the first symptoms to appear were classified as moderate. In many cases plants died, particularly at the higher temperatures and toward the end of the experiment. Whether these plants died as a result of mosaic infection or from other causes is not known, although non-inoculated plants were similarly affected.

## CHAPTER IV

### RESULTS

The first experiment was planted October 19, 1963, and inoculated on November 15, 1963. Following inoculation, the plants were moved to the greenhouse rooms indicated previously. Light intensity could not be controlled well and was somewhat less, due to shading, in the room held at 19° C than at the other two temperatures. Day length, however, was approximately equal at all temperatures.

Growth at 19° C was rather slow compared with the plants held at higher temperatures. The expression of wheat streak-mosaic virus symptoms was slight compared with symptom expression at the higher temperatures. Data were first recorded 12 days following inoculation (Table I) at which time symptoms were evident in the variety Comanche, the Cch x Tst-Pn<sup>2</sup> selection, and the P3-19 selection. The nature of the symptoms was so mild that it was sometimes difficult to make a positive identification. Symptom development proceeded so slowly that no further data were recorded until 30 days after inoculation. At that time a few plants of Gage and Comanche had symptoms, and one plant of Concho had developed definite, but mild, symptoms. The symptoms observed in the Cch x Tst-Pn<sup>2</sup> and the P3-19 selections could no longer be seen. It is possible that the symptoms observed in these selections earlier were not a result of the wheat streak-mosaic infection.

TABLE I

PERCENT OF PLANTS OF SEVERAL VARIETIES AND SELECTIONS OF WHEAT  
WITH MILD, MODERATE AND SEVERE SYMPTOMS FOLLOWING  
INOCULATION WITH THE WHEAT STREAK-MOSAIC VIRUS  
AND HELD AT 19° C

Days after inoculation	Percent of plants showing mild (m), moderate (M), and severe (S) symptoms																				
	Gage			Ponca			Comanche			Mql <sup>a</sup> -Oro x Pn			Concho			Cch x Tst-Pn <sup>2</sup>			Sel. P3-19		
	m	M	S	m	M	S	m	M	S	m	M	S	m	M	S	m	M	S			
12	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	10	0	0	2	0	0
30	9	0	0	0	0	0	8	0	0	0	0	0	1	0	0	0 <sup>b</sup>	0	0	0 <sup>b</sup>	0	0

<sup>a</sup>Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52: 613, 1960 and U. S. Dept. of Agr. Tech. Bull. 1278, p. 131, 1963.

<sup>b</sup>Symptoms observed at 12 days after inoculations could no longer be seen 30 days after inoculation and it is possible that the symptoms observed at 12 days were not a result of wheat streak-mosaic infection.

It is interesting to note that at a temperature of 19° C only the field-susceptible varieties Comanche and Gage and the field-tolerant variety Concho had developed any positive symptoms. No attempt was made to recover the virus from plants not showing symptoms since plants inoculated at the same time and held at higher temperatures had a higher percentage of infection, indicating that the method of inoculation was effective.

Among the plants held at 22° C, symptoms first appeared in the field-susceptible varieties Gage and Ponca after four days, Comanche and the Mql - Oro x Pn selection after five days, in the field-tolerant varieties Concho and the Cch x Tst-Pn<sup>2</sup> selections after eight days, and in the field-resistant P3-19 selection after 15 days (Table II).

Plant growth and symptom expression 12 days after inoculation had shown considerable progress at 22° C compared with 19° C (Table III). Only mild symptoms were observed after 12 days, but the percent of plants with symptoms was far greater than at the lower temperature. For example, 96 percent of the plants of the variety Gage had developed symptoms at the end of 12 days. Among the other field-susceptible varieties the Mql-Oro x Pn selection had 71 percent, Comanche 63 percent and Ponca 14 percent of plants showing mild symptoms at the end of 12 days. Concho, considered field-tolerant, had 84 percent of the plants with mild symptoms, but the other field-tolerant strain the Cch x Tst-Pn<sup>2</sup> selection, had only 15 percent. Even the field-resistant P3-19 selection had 11 percent of the plants with mild symptoms. After 30 days, symptoms in most of the varieties had progressed to the moderate classification or higher, except in the plants of the Cch x Tst-Pn<sup>2</sup> selection, and P3-19

TABLE II  
 INCUBATION PERIOD OF THE WHEAT STREAK-MOSAIC  
 DISEASE IN SEVERAL VARIETIES AND SELEC-  
 TIONS OF WHEAT HELD AT DIFFERENT  
 TEMPERATURES AFTER INOCU-  
 LATION

Variety or Selection	Incubation period (inoculation to first symptom expression) in days at:		
	19° C	22° C	27° C
Gage	± 30	4	4
Ponca	-	4	4
Comanche	± 12	5	4
Mql <sup>a</sup> -Oro x Pn	-	5	4
Concho	± 30	8	6
Cch x Tst-Pn <sup>2</sup>	± 12 <sup>b</sup>	8	6
P3-19 selection	± 12 <sup>b</sup>	15	12

<sup>a</sup>Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52:613, 1960, and U. S. Dept. of Agri. Tech. Bull. 1273, p. 131, 1963.

<sup>b</sup>Symptoms observed 12 days after inoculation could no longer be seen 30 days after inoculation, and it is possible that the symptoms observed at 12 days were not a result of wheat streak-mosaic virus infection.

TABLE III

PERCENT OF PLANTS OF SEVERAL VARIETIES AND SELECTIONS OF WHEAT WITH MILD, MODERATE AND SEVERE SYMPTOMS FOLLOWING INOCULATION WITH THE WHEAT STREAK-MOSAIC VIRUS AND HELD AT 22° C

Days after inoculation	Percent of plants showing mild (m), moderate (M) and severe (S) symptoms																				
	Gage			Ponca			Comanche			Mql <sup>a</sup> -Oro x Pn			Concho			Cch x Tst-Pn <sup>2</sup>			Sel. P3-19		
	m	M	S	m	M	S	m	M	S	m	M	S	m	M	S	m	M	S	m	M	S
12	96	0	0	14	0	0	63	0	0	71	0	0	84	0	0	15	0	0	11	0	0
24	100	0	0	14	0	0	63	0	0	71	0	0	87	0	0	18	0	0	11	0	0
30	0	16	84	45	21	0	0	55	41	7	89	0	0	100	0	4	1	2 <sup>b</sup>	14	4	0

<sup>a</sup>Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52:613, 1960, and U. S. Dept. of Agr. Tech. Bull. 1278, p. 131, 1963.

<sup>b</sup>A decrease in the total percent of plants with symptoms from 24 to 30 days after inoculation was caused by the death of some plants. It is not known whether these plants died as a result of virus infection or from some other cause.

selection and, strangely, Ponca. Severe symptoms had developed in 84 percent of the plants of Gage, 41 percent of the plants of Comanche and two percent of the Cch x Tst-Pn<sup>2</sup> selection.

Symptoms first appeared in each of the field-susceptible varieties four days after inoculation when the plants were held at 27° C. The incubation period in the field-tolerant varieties was six days and in the field-resistant variety was 12 days at this temperature, which represents a slight decrease in incubation period over plants held at 22° C (Table II).

Growth at the 27° C temperature was initially rapid and mild symptoms appeared early in a high percentage of most varieties (Table IV). Even the P3-19 selection had 25 percent of the plants with mild symptoms after 12 days. The only exception was the Mql-Oro x Pn selection, where only six percent of the plants had symptoms at 12 days. The growth of this variety at this temperature, however, was poor from the start of the study.

There did not appear to be any appreciable difference in the over all symptom expression at 27° C and 22° C, except that there was a slightly higher percent of plants showing mild symptoms at the end of 12 days than at the higher temperature.

However, the symptom development proceeded at a more rapid rate at the higher temperature. All of the varieties, at the end of 30 days, had developed a higher percentage of plants with symptoms at 27° C than at the lower temperatures. In addition, more of the plants developed symptoms classified as moderate or severe. This was particularly true of the field-tolerant Concho, the Cch x Tst-Pn<sup>2</sup> selection and the field-resistant P3-19 selection.



TABLE IV

PERCENT OF PLANTS OF SEVERAL VARIETIES AND SELECTIONS  
OF WHEAT WITH MILD, MODERATE AND SEVERE SYMPTOMS  
FOLLOWING INOCULATION WITH THE WHEAT STREAK-  
MOSAIC VIRUS AND HELD AT 27° C

Days after inoculation	Percent of plants showing mild (m), moderate (M) and severe (S) symptoms																				
	Gage			Ponca			Comanche			Mql <sup>a</sup> -Oro x Pn			Concho			Cch x Tst-Pn <sup>2</sup>			Sel. P3-19		
	m	M	S	m	M	S	m	M	S	m	M	S	m	M	S	m	M	S	m	M	S
12	100	0	0	24	0	0	97	0	0	6	0	0	39	0	0	40	0	0	25	0	0
24	100	0	0	24	0	0	97	0	0	9	0	0	39	0	0	44	0	0	25	0	0
30	0	2	98	0	54	31	0	99	0	40	60	0	0	71	29	18	24	25	37	9	0

<sup>a</sup>Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52:613, 1960, and U. S. Dept. of Agri. Tech. Bull. 1278, p. 131, 1963.

An attempt was then made to repeat the experiment, but preliminary temperature measurements indicated that the lowest temperature (19° C) could not be maintained. Consequently, only two temperatures, 21° C and 27° C, were used. As indicated previously, the actual temperatures averaged 24° C and 29° C, respectively.

This second study was planted February 23, 1964, and the plants were inoculated on March 18, 1964. Following inoculation, the plants were moved to the greenhouse rooms as in the previous experiment.

The incubation periods at 24° C and 29° C, given in Table V, were essentially the same as they were at 22° C and 27° C, respectively, in the first experiment. Symptoms were somewhat slower to appear in the variety Gage at 24° C, but still appeared earlier in this variety than they did in Concho, the Cch x Tst-Pn<sup>2</sup> selection, or the P3-19 selection.

The growth rate of the plants at 24° C was quite rapid, similar to the rates obtained at 22° C and 27° C in the first experiment. The development of symptoms, however, was even more rapid. Moderate symptoms had developed in all varieties except the P3-19 selection at the end of 12 days. These results are given in Table VI. Symptom expression continued to progress at a rapid rate and at the end of 30 days severe symptoms were expressed in over half of all of the varieties in the test except the P3-19 selection. All of the plants at this temperature were held an additional ten days, and at the end of that time all of the plants that remained alive showed severe symptoms except, again, the P3-19 selection. Only approximately

TABLE V

INCUBATION PERIOD OF THE WHEAT STREAK-MOSAIC  
DISEASE IN SEVERAL VARIETIES AND SELECTIONS OF  
WHEAT HELD AT DIFFERENT TEMPERATURES  
AFTER INOCULATION

Variety or Selection	Incubation period (inoculation to first symptom expression) in days at:	
	24° C	29° C
Gage	6	4
Ponca	4	4
Comanche	5	4
Mql <sup>a</sup> -Oro x Pn	5	4
Concho	8	6
Cch x Tst-Pn <sup>2</sup>	8	5
P3-19 selection	15	12

<sup>a</sup>Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52:613, 1960, and U. S. Dept. of Agr. Tech. Bull. 1278, p. 131, 1963.

TABLE VI

PERCENT OF PLANTS OF SEVERAL VARIETIES AND SELECTIONS OF WHEAT WITH MILD, MODERATE AND SEVERE SYMPTOMS FOLLOWING INOCULATION WITH THE WHEAT STREAK-MOSAIC VIRUS AND HELD AT 24° C.

Days after Inoculation	Percent of plants showing mild (m), moderate (M), and severe (S) symptoms																				
	Gage			Ponca			Comanche			Mql <sup>a</sup> -Oro x Pn		Concho			Cch x Tst-Pn <sup>2</sup>			Sel. P3-19			
	m	M	S	m	M	S	m	M	S	m	M	m	M	S	m	M	S	m	M	S	
12	0	89	0	0	80	0	0	95	0	76	10	0	0	95	5	9	7	0	0	0	0
24	0	52	48	0	50	49	0	50	49	0	45	54	0	54	46	57	43	0	0	0	0
30	0	32	68	0	29	71	0	28	72	0	30	70	0	31	69	0	38	62	0	9	0
40	0	0	51 <sup>b</sup>	0	0	90 <sup>b</sup>	0	0	80 <sup>b</sup>	0	0	85 <sup>b</sup>	0	0	82 <sup>b</sup>	0	0	95 <sup>b</sup>	0	9	0

<sup>a</sup>Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52:613, 1960, and U. S. Dept. of Agr. Tech. Bull. 1278, p. 131, 1963.

<sup>b</sup>A decrease in the total percent of plants with symptoms from 30 to 40 days after inoculation was caused by the death of some plants. It is not known whether these plants died as a result of virus infection or from some other cause.

ten percent of the plants of this selection developed symptoms, and, even after 40 days, these symptoms were classed only as moderate.

Plants held at the 29° C temperature made rather poor growth from the beginning. This did not, however, seem to impede significantly the development of symptoms of wheat streak-mosaic. Over 90 percent of the plants of all varieties except the Cch x Tst-Pn<sup>2</sup> and the P3-19 selections were showing at least mild symptoms at the end of 12 days (Table VII). In the Mql-Oro x Pn and the Cch x Tst-Pn<sup>2</sup> and the P3-19 selections a few symptoms were classified as moderate, even at this early date. Disease development progressed rapidly, and after 24 days over half of all of the varieties, including the Cch x Tst-Pn<sup>2</sup> and P3-19 selections were showing moderate to severe symptoms. The expression of symptoms was not much more severe after 30 days than they had been after 24 days; however, many of the plants with severe symptoms were near death.

After the plants had been held at these temperatures for 30 days it became necessary to vacate the space. It seemed desirable, however, to determine if the symptoms of the plants of the P3-19 selection which were classified as only moderate at that time would continue to develop. Consequently, 52 plants of this selection were placed in an adjacent greenhouse room where the temperature was not controlled. The temperature averaged approximately 31° C, but occasionally reached as high as 38° C in the mid-afternoon. The plants were held at this temperature for an additional 14 days.

The symptoms in these plants continued to develop, and at the end of seven days 58 percent of the plants had symptoms classified as severe, and after 14 days 100 percent of the plants exhibited severe

TABLE VII

PERCENT OF PLANTS OF SEVERAL VARIETIES AND SELECTIONS OF WHEAT WITH MILD, MODERATE AND SEVERE SYMPTOMS FOLLOWING INOCULATION WITH THE WHEAT STREAK-MOSAIC VIRUS AND HELD AT 24° C.

Days after Inoculation	Percent of plants showing mild (m), moderate (M), and severe (S) symptoms																				
	Gage			Ponca			Comanche			Mql <sup>a</sup> -Oro x Pn			Concho			Cch x Tst-Pn <sup>2</sup>			Sel. P3-19		
	m	M	S	m	M	S	m	M	S	m	M	S	m	M	S	m	M	S	m	M	S
12	0	95	0	0	95	0	0	95	0	80	15	0	0	95	0	16	2	0	0	0	0
24	0	24	76	0	19	81	0	28	72	0	17	83	0	26	74	0	13	87	0	61	39
30	0	21	79	0	19	81	0	26	74	0	17	83	0	26	74	0	13	87	0	57	43

<sup>a</sup> Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52:613, 1960, and U. S. Dept. of Agr. Tech. Bull. 1278, p. 131, 1963.

symptoms and many had died. These data are shown in Table VIII.

The profound influence of temperature on the development of symptoms of wheat streak-mosaic, particularly in varieties thought to be field-tolerant or field-resistant, indicated the need for studies with more refined temperature control. Therefore, a third study was planted on October 28, 1964, and the plants were inoculated on November 14, 1964. Following inoculation, the plants were moved to growth chambers where the temperatures were well controlled. Four chambers were used, one being held at each of the following temperatures: 24° C, 29° C, 35° C, and one held at 32° C when the lights were on and 21° C when the lights were off. Light intensity was approximately 3,000 to 3,500 ft. candles with a day length of 12 hours for each chamber. Plants in three pots of each variety were inoculated and plants in another two pots served as controls.

The plants were observed for symptom expression for 15 days after inoculation. Each plant exhibiting symptoms was classified as having mild, moderate, or severe symptoms.

At the lowest temperature used (24° C) symptoms were first expressed in the variety Gage in four days (Table IX) which is comparable with the results obtained in the first experiment in the greenhouse at approximately the same temperature. However, the symptoms first appeared in Concho, and the Cch x Tst-Pn<sup>2</sup> selection in five days, which was three days earlier than at comparable temperatures in the greenhouse. The incubation period for these varieties in the growth chamber at 24° C was more comparable to temperatures of 27° C and 29° C in the greenhouse. Similarly, symptoms first appeared in the P3-19 selection in six days, but the incubation period for this

TABLE VIII

PERCENT OF PLANTS OF WHEAT SELECTION P3-19<sup>a</sup>  
 WITH MILD, MODERATE OR SEVERE SYMPTOMS  
 FOLLOWING INOCULATION WITH THE WHEAT STREAK-  
 MOSAIC VIRUS AND HELD 30 DAYS AT 29° C  
 AND SUBSEQUENTLY AT 31° C

Days after transfer from 29° C	Percent of plants with mild (m), moderate (M), and severe (S) symptoms		
	m	M	S
0	0	100	0
7	0	42	58
10	0	23	77
14	0	0	100

<sup>a</sup>A selection from the cross Triticum sp x Agropyron elongatum  
 2x Arlando x Triticum timopheevi 3x Hope x Baart 4x Nebred.



TABLE IX

INCUBATION PERIOD OF THE WHEAT STREAK-MOSAIC  
DISEASE IN SEVERAL VARIETIES AND SELEC-  
TIONS OF WHEAT HELD AT DIFFERENT  
TEMPERATURES AFTER INOCULATION

Variety or Selection	Incubation period (inoculation to first symptom expression) in days at:			
	24° C	29° C	35° C	day 32° C night 21° C
Gage	4	3	8	6
Concho	5	5	7	6
Cch <sup>a</sup> x Tst-Pn <sup>2</sup>	5	4	7	6
P3-19 selection	6	6	7	6

<sup>a</sup>Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52:613, 1960, and U. S. Dept. of Agr. Tech. Bull. 1278, p. 131, 1963.

selection in the greenhouse was double this figure even at the higher temperatures of 27° C and 29° C.

The highest percentage of plants showing symptoms in Gage and the Cch x Tst-Pn<sup>2</sup> selection was reached at the end of seven days, with 100 percent and 66 percent, respectively, (Table X). The maximum percent of the Concho plants showing symptoms was not reached until eight days after inoculation at a level of 100 percent and the maximum percent of the P3-19 selection plants showing infection was not reached until 12 days at a level of 61 percent.

The progress of symptom development was rapid and at the end of 15 days 100 percent of the plants of Gage were exhibiting severe symptoms. In Concho, 88 percent of the plants had severe symptoms and 12 percent were classified as moderate. All of the plants of the Cch x Tst-Pn<sup>2</sup> selection which developed symptoms had reached the severe stage of symptom expression at the end of 15 days. Almost the same could be said of the P3-19 selection when 53 percent of the plants were classified with severe symptoms and eight percent moderate symptoms at the end of 15 days. A comparison of the development of symptoms between variety Gage and the P3-19 selection is illustrated graphically in Figure 1.

Growth at this temperature was excellent, although somewhat slower than at 29° C. None of the control plants became infected, and a comparison between the growth of the control plants and those that were inoculated indicated that there was very little in the way of stunting in these infected plants.

The incubation period at 29° C was the same for the variety Concho and the P3-19 selection as it was at 24° C (Table IX). Symptoms

TABLE X

PERCENT OF PLANTS OF SEVERAL VARIETIES AND SELECTIONS OF WHEAT WITH MILD, MODERATE AND SEVERE SYMPTOMS FOLLOWING INOCULATION WITH THE WHEAT STREAK-MOSAIC VIRUS AND HELD AT 24° C

Days after Inoculation	Percent of plants showing mild (m), moderate (M), and severe (S) symptoms											
	Gage			Concho			Cch <sup>a</sup> x Tst-Pn <sup>2</sup>			Sel. P3-19		
	m	M	S	m	M	S	m	M	S	m	M	S
3	0	0	0	0	0	0	0	0	0	0	0	0
4	30	0	0	0	0	0	0	0	0	0	0	0
5	84	0	0	90	0	0	22	0	0	0	0	0
6	84	0	0	90	0	0	66	0	0	7	0	0
7	15	46	38	0	70	20	0	66	0	15	7	0
8	0	23	77	0	60	40	0	66	0	15	23	0
9	0	16	84	0	60	40	0	33	33	0	23	15
10	0	16	84	0	40	60	0	33	33	0	23	23
11	0	0	100	0	23	77	0	22	44	0	15	38
12	0	0	100	0	23	77	0	22	44	0	15	46
13	0	0	100	0	23	77	0	11	55	0	15	46
14	0	0	100	0	12	88	0	0	66	0	15	46
15	0	0	100	0	12	88	0	0	66	0	8	53

<sup>a</sup>Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52:613, 1960, and U. S. Dept. of Agr. Tech. Bull. 1278 p. 131, 1963.

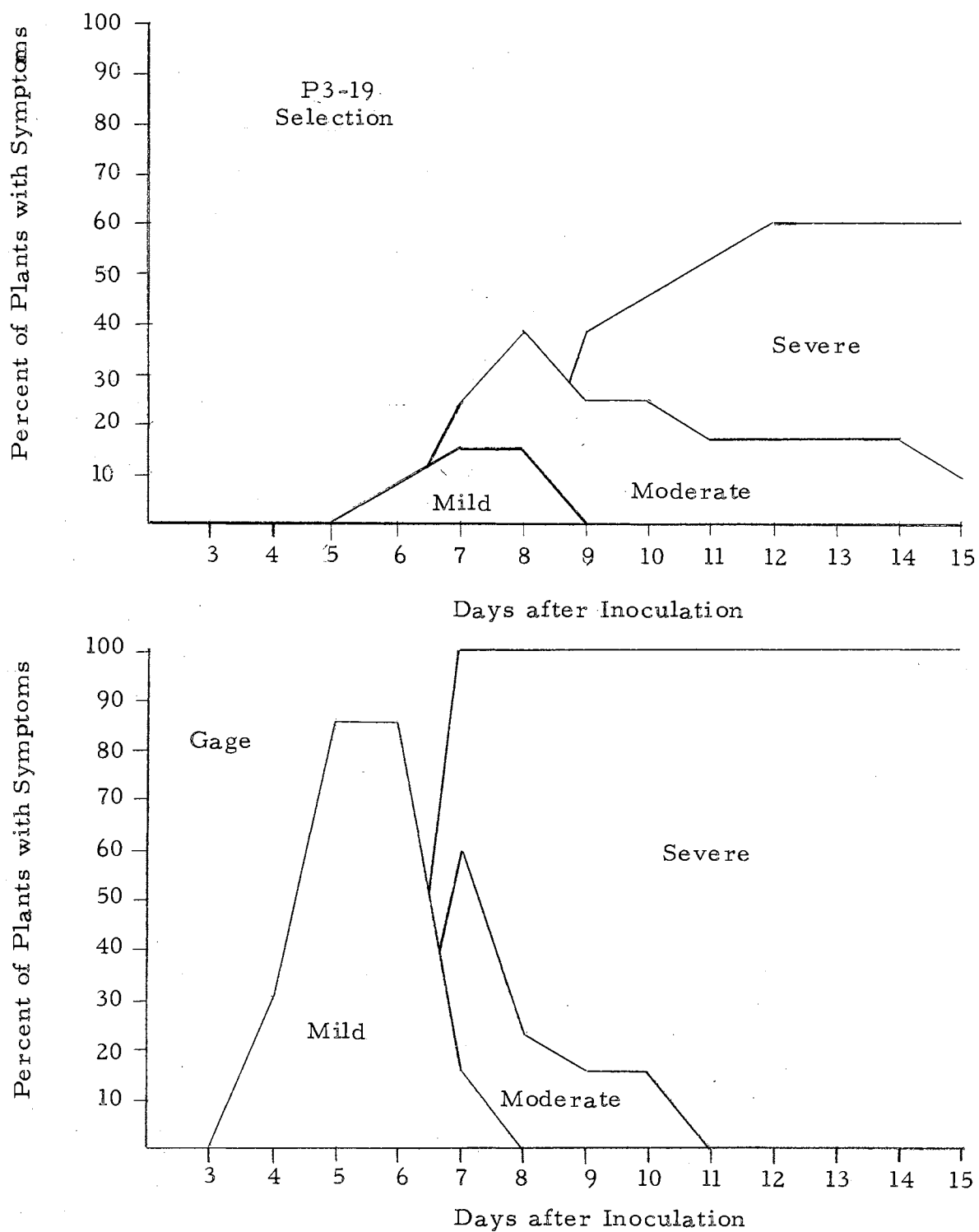


FIGURE 1: THE PERCENT OF PLANTS OF THE VARIETY GAGE AND THE P3-19 SELECTION WITH MILD, MODERATE AND SEVERE SYMPTOMS WITHIN 15 DAYS AFTER INOCULATION AT 24° C.

in the variety Gage and the Cch x Tst-Pn<sup>2</sup> selection appeared 24 hours earlier at 29° C than they did at 24° C. For the variety Gage, the incubation period was three days, which is the shortest period yet reported for any wheat variety.

All of the plants which ultimately developed symptoms had done so at the end of the eight days (Table XI). This was approximately the same time period involved at 24° C, except for the P3-19 selection which required 12 days at 24° C. All of the Concho and the Cch x Tst-Pn<sup>2</sup> selection plants developed symptoms, but only 84 percent of the Gage plants and 83 percent of the P3-19 selection plants did so. Symptom development proceeded at about the same rate as at 24° C, except, again, the P3-19 selection where it was more rapid at 29° C. A comparison of symptom development in the variety Gage and the P3-19 selection is shown in Figure 2.

Plant growth was better at 29° C than it was at any other temperature used, but some stunting of inoculated plants was evident when compared to the controls, particularly toward the end of the test when many of the plants with severe symptoms had begun to deteriorate. No symptoms were observed in any of the non-inoculated plants.

At 35° C the growth of the plants was very poor. After 12 days at this temperature many plants were dying, even among those not inoculated. Symptoms began to become evident in all varieties at about seven or eight days after inoculation (Table IX). Most of the plants grew so slowly and symptoms developed so poorly that even after 15 days none of the symptoms were classified as severe (Table XII). There was very little, if any, difference in varietal response. Some plants of all the varieties were ultimately classified with

TABLE XI

PERCENT OF PLANTS OF SEVERAL VARIETIES AND SELECTIONS OF WHEAT WITH MILD, MODERATE AND SEVERE SYMPTOMS FOLLOWING INOCULATION WITH THE WHEAT STREAK-MOSAIC VIRUS AND HELD AT 29° C.

Days after Inoculation	Percent of plants showing mild (m), moderate (M) and severe (S) symptoms											
	Gage			Concho			Cch <sup>a</sup> xTst-Pn <sup>2</sup>			Sel. P3-19		
	m	M	S	m	M	S	m	M	S	m	M	S
3	23	0	0	0	0	0	0	0	0	0	0	0
4	38	0	0	0	0	0	33	0	0	0	0	0
5	69	0	0	45	0	0	77	0	0	0	0	0
6	61	8	0	72	0	0	88	0	0	25	0	0
7	53	16	0	72	20	0	0	99	0	33	0	0
8	38	46	0	0	90	10	0	75	25	75	8	0
9	0	69	15	0	80	20	0	75	25	0	58	25
10	0	69	15	0	80	20	0	75	25	0	50	33
11	0	46	38	0	70	30	0	62	38	0	33	50
12	0	46	38	0	60	40	0	62	38	0	16	67
13	0	30	54	0	40	60	0	60	40	0	16	67
14	0	23	61	0	40	60	0	20	80	0	8	75
15	0	7	77	0	20	80	0	0	100	0	8	75

<sup>a</sup>Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52:913, 1960, and U. S. Dept. of Agr. Tech. Bull. 1278, p. 131, 1963.

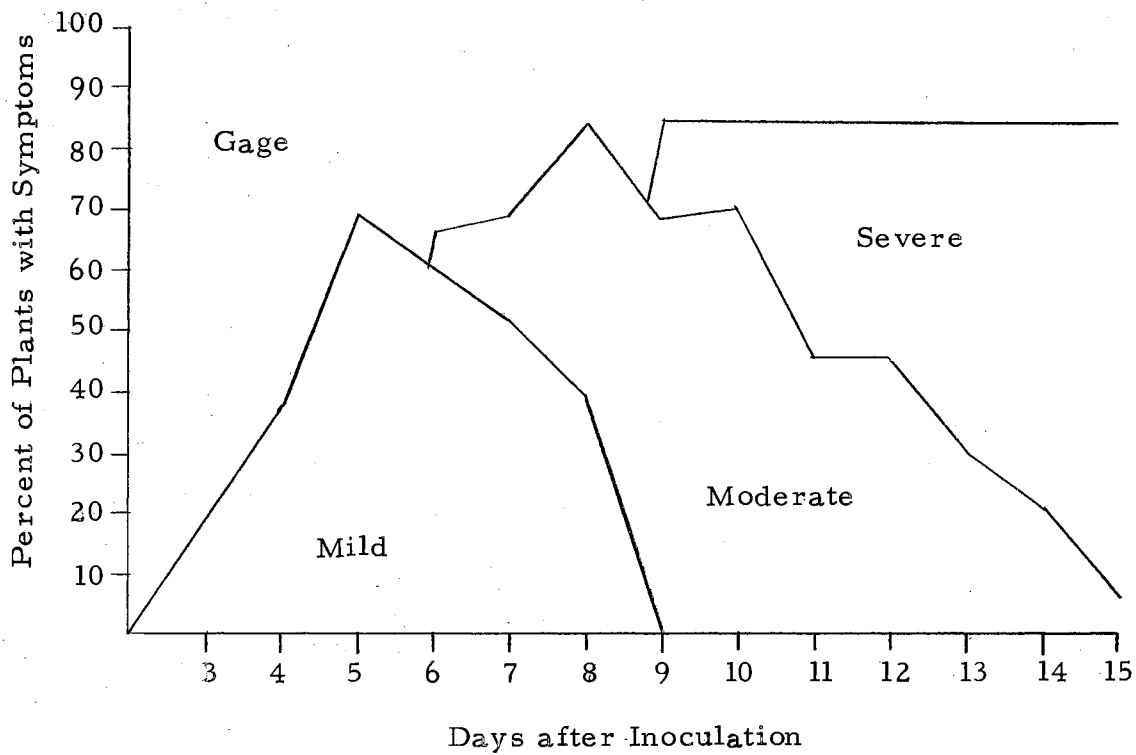
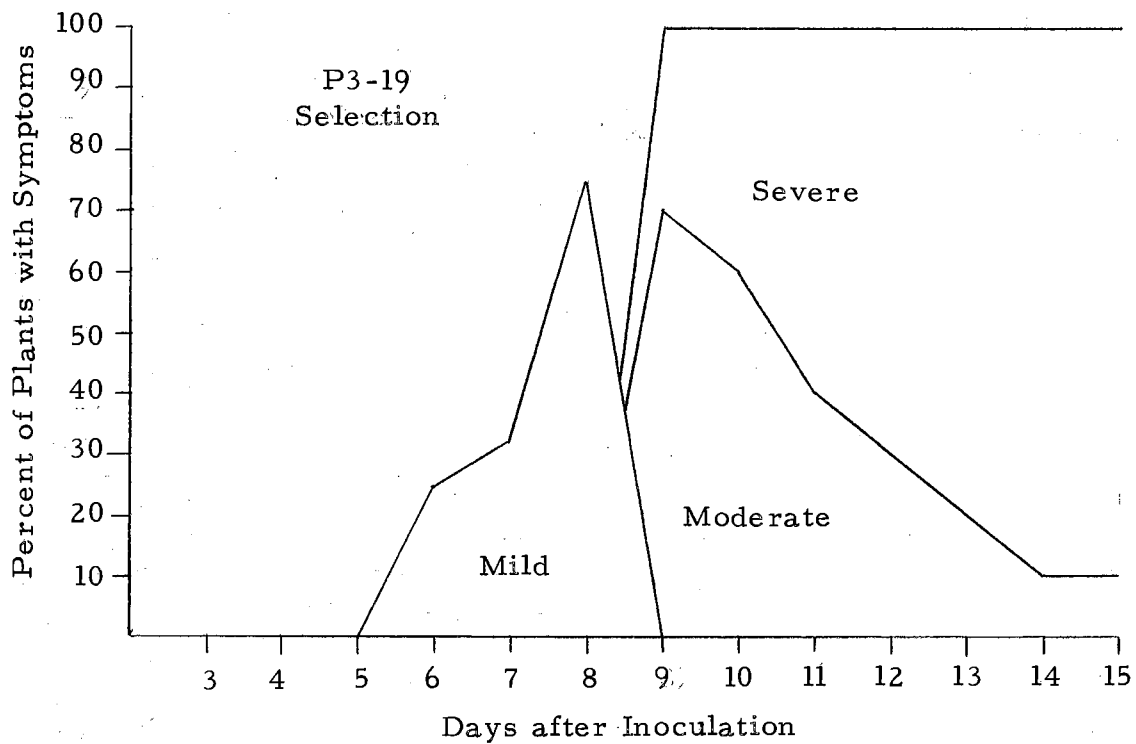


FIGURE 2: THE PERCENT OF PLANTS OF THE VARIETY GAGE AND THE P3-19 SELECTION WITH MILD, MODERATE AND SEVERE SYMPTOMS WITHIN 15 DAYS AFTER INOCULATION AT 29° C.

TABLE XII

PERCENT OF PLANTS OF SEVERAL VARIETIES AND SELECTIONS OF WHEAT WITH MILD, MODERATE AND SEVERE SYMPTOMS FOLLOWING INOCULATION WITH THE WHEAT STREAK-MOSAIC VIRUS AND HELD AT 35° C.

Days after Inoculation	Percent of plants showing mild (m), moderate (M) and severe (S) symptoms											
	Gage			Concho			Cchax Tst-Pn <sup>2</sup>			Sel. P3-19		
	m	M	S	m	M	S	m	M	S	m	M	S
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	8	0	0	10	0	0	8	0	0
8	15	0	0	8	0	0	40	0	0	33	0	0
9	38	7	0	16	0	0	60	0	0	33	0	0
10	38	7	0	25	0	0	60	0	0	58	0	0
11	38	7	0	25	0	0	60	0	0	66	0	0
12	40 <sup>b</sup>	0	0	25	0	0	50 <sup>b</sup>	0	0	66 <sup>b</sup>	0	0
13	40	0	0	33	0	0	50	0	0	55 <sup>b</sup>	0	0
14	30	10	0	16	16 <sup>b</sup>	0	12	37	0	33	22	0
15	30	10	0	16	16	0	12	37	0	28	14	0

<sup>a</sup>Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52:613, 1960, and U. S. Dept. of Agr. Tech. Bull. 1278, p. 131, 1963.

<sup>b</sup>A decrease in the total percent of plants with symptoms from 11 to 15 days after inoculation was caused by the death of some plants. It is not known whether these plants died as a result of virus infection or from some other cause.



moderate symptoms. Although none of the inoculated plants developed symptoms, growth was poor and no stunting of the inoculated plants was evident. The development of symptoms in Gage and the P3-19 selection at 35° C was compared in the Figure 3.

In the chamber with 12-hour diurnal cycle at 32° C with lights and 21° C without lights, the incubation period for all varieties was six days (Table IX). The maximum percent of plants with symptoms had been reached by seven days after inoculation in the varieties Gage and Concho, eight days in the P3-19 selection and ten days in the Cch x Tst-Pn<sup>2</sup> selection (Table XIII). The development of symptoms progressed in a manner comparable to the plants held at a constant temperature of 29° C, except that in the varieties Concho and the P3-19 selection many more plants retained moderate symptoms with the diurnal cycle than at the constant temperature. A comparison of the development of symptoms in the variety Gage and the P3-19 selection is shown in Figure 4.

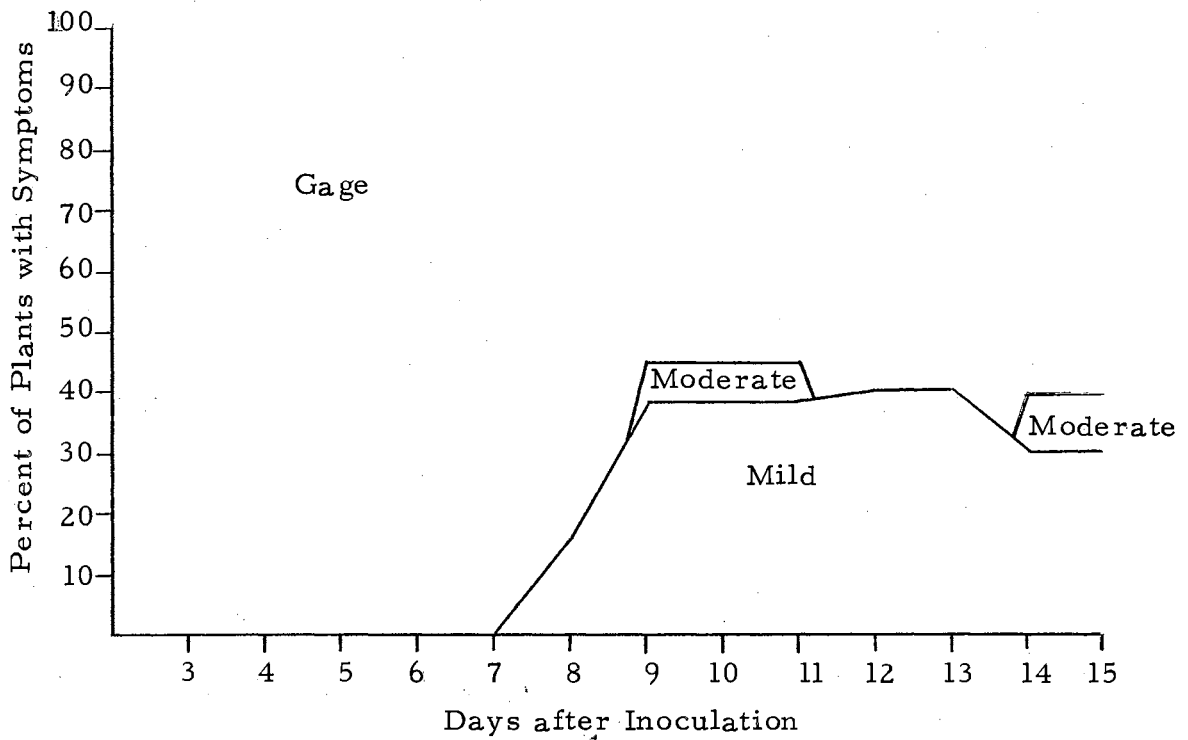
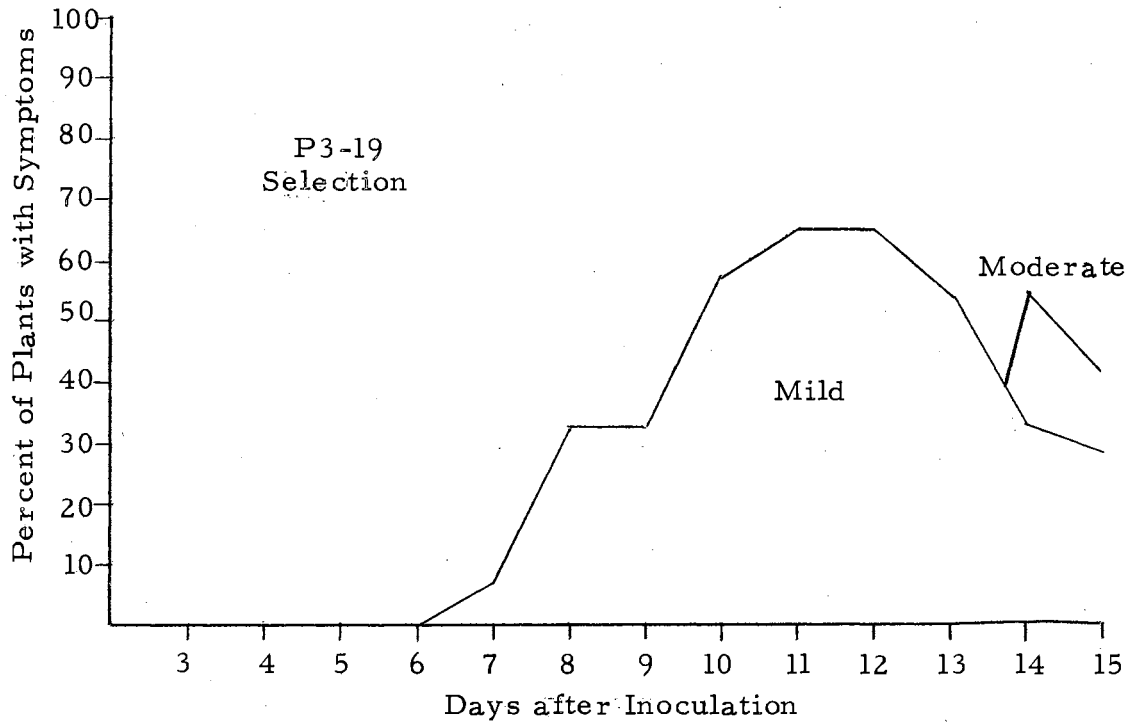


FIGURE 3: THE PERCENT OF PLANTS OF THE VARIETY GAGE AND THE P3-19 SELECTION WITH MILD, MODERATE AND SEVERE SYMPTOMS WITHIN 15 DAYS AFTER INOCULATION AT 35° C.

TABLE XIII

PERCENT OF PLANTS OF SEVERAL VARIETIES AND SELECTIONS OF WHEAT WITH MILD, MODERATE AND SEVERE SYMPTOMS FOLLOWING INOCULATION WITH THE WHEAT STREAK-MOSAIC VIRUS AND HELD AT 32° C WITH LIGHTS (12 HOURS) AND 21° C WITHOUT LIGHTS (12 HOURS).

Days after Inoculation	Percent of plants showing mild (m), moderate (M) and severe (S) symptoms											
	Gage			Concho			Cch <sup>a</sup> x Tst-Pn <sup>2</sup>			Sel. P3-19		
	m	M	S	m	M	S	m	M	S	m	M	S
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	90	0	0	76	0	0	44	0	0	20	0	0
7	90	10	0	92	0	0	77	0	0	30	0	0
8	40	60	0	92	0	0	77	0	0	100	0	0
9	40	60	0	69	15 <sup>b</sup>	0	11	66	0	90	10	0
10	0	80	20	69	15	0	22	44	22	77	12	11
11	0	80	20	61	23	0	0	44	44	77	12	11
12	0	60	40	61	23	0	0	33	55	44	44	12
13	0	50	50	61	8	15	0	22	66	0	88	12
14	0	50	50	39	30	15	0	11	77	0	77	23
15	0	40	60	0	69	15	0	11	77	0	77	23

<sup>a</sup>Abbreviations used were made according to rules adopted by the National Wheat Improvement Committee. See Agron. J. 52:613, 1960, and U. S. Dept. of Agr. Tech. Bull. 1278, p. 131, 1963.

<sup>b</sup>A decrease in the total percent of plants with symptoms from 8 to 15 days after inoculation was caused by the death of some plants. It is not known whether these plants died as a result of virus infection or from some other cause.

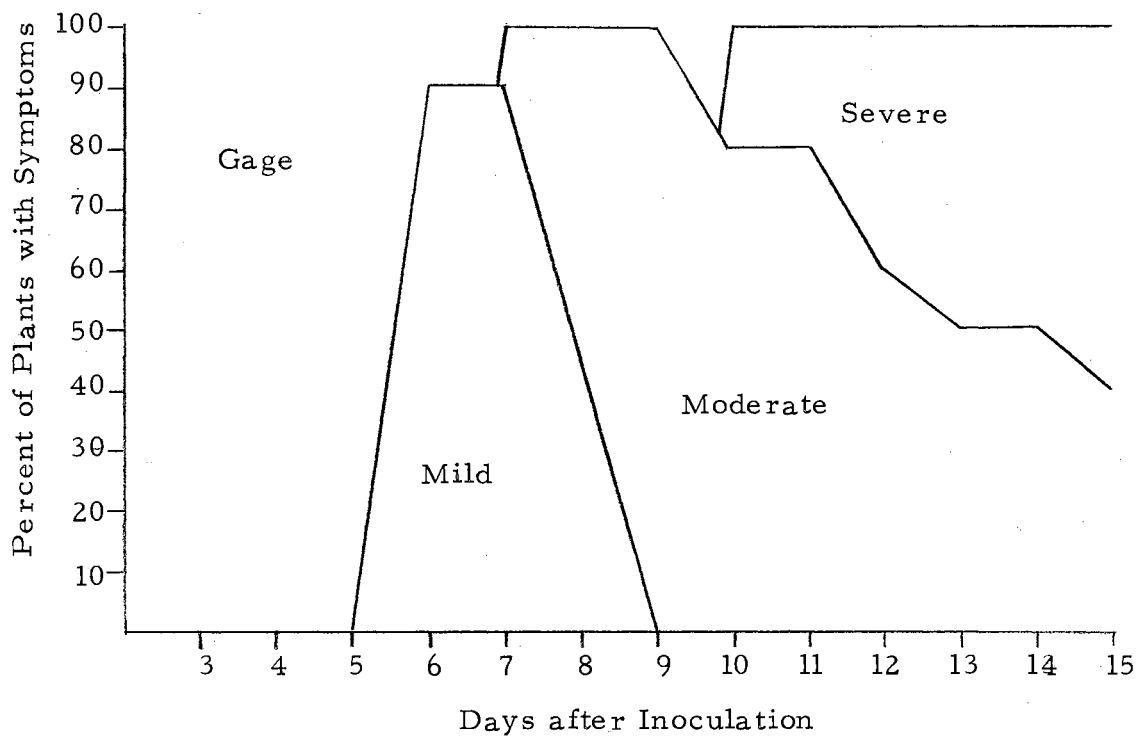
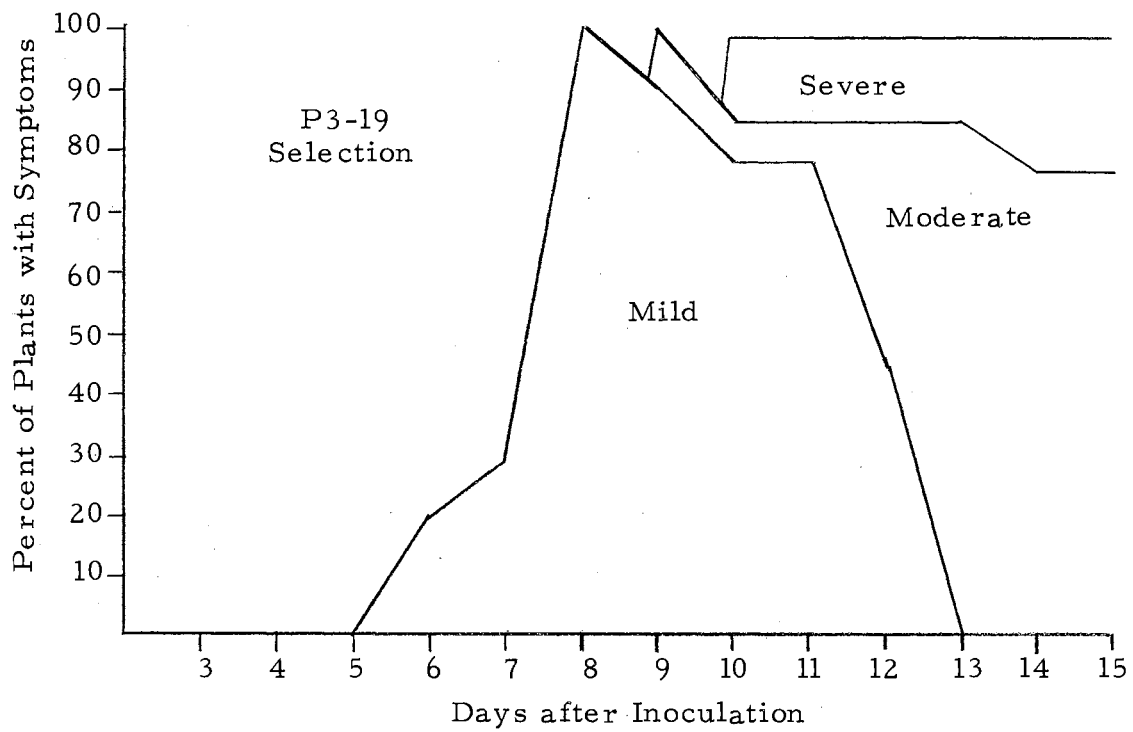


FIGURE 4: THE PERCENT OF PLANTS OF THE VARIETY GAGE AND THE P3-19 SELECTION WITH MILD, MODERATE AND SEVERE SYMPTOMS WITHIN 15 DAYS AFTER INOCULATION AT 32° C WITH LIGHTS (12 HRS) AND 21° C WITHOUT LIGHTS (12 HRS).

## CHAPTER V

### DISCUSSION

The results obtained in this study support well the findings of McKinney (6) in that as the temperature was increased the incubation period for the wheat streak-mosaic in wheat was shortened. In fact, with the optimum condition used in this study (29° C) the incubation period was only three days - the shortest yet reported for this virus disease in wheat. Although McKinney attached little or no significance to the shortening of the incubation period, it was of interest that in practically all cases, regardless of temperature except at the extremes, the varieties that were susceptible in the field had the shorter incubation periods when compared to varieties that are field-tolerant or field resistant. Therefore, the length of the incubation period may be a useful tool in measuring the tolerance or resistance of a variety. If so, the temperature used in the testing process assumes significance if one test is to be compared with another.

The results also confirm the findings of Sill and Fellows (13) in as much as severe symptom expression took place more readily and more rapidly as the temperature was increased. In addition, the use of field-resistant, field-tolerant and field-susceptible varieties in this study afforded an opportunity to make a comparison of the development of symptoms in these types of varieties. It was found that in general, the more field-tolerant or resistant the variety

was, the more slowly it developed severe symptoms. As the temperature was increased, however, the difference in rapidity of severe symptom expression between field-susceptible and field-resistant varieties was narrowed. Therefore, if the characteristic of rapidity of severe symptoms expression is to be used as a measure of field reaction, temperature again becomes important. These results also tend to support Bawden (1) in that the severity of symptoms may be related to virus content, and that temperature is an important consideration in virus development within the plant with this disease.

Another evident fact derived from this study was that there appeared to be temperature extremes beyond which the virus does not develop well within the plant, if symptom expression is correlated with virus development. The wheat plants grew slowly but developed well at 19° C but there was very little symptom expression at this temperature. At 35° C the wheat plants did not grow well, even in the absence of the virus, and the inoculated plants never did express severe symptoms.

It is quite possible that the selection of the Triticum sp x Agropyron elongatum cross (P3-19) used in this study, did not contain the gene or genes for resistance to the wheat streak-mosaic virus that was reported by McKinney and Sando (8), Schmitt et. al. (1), or Sebesta and Bellingham (9). In these studies, at least, this selection did not express resistance at any temperature, if resistance is limited to the absence of symptoms or to a local lesion type reaction. This selection did possess the characteristics of delayed incubation and relatively slow development of symptom severity and this field-resistant selection displayed these character-

istics to a higher degree than the field-tolerant varieties. It is evident that more work needs to be done relative to the resistance and/or, tolerance contained in the selections of these Triticum sp x Agropyron elongatum crosses.

## CHAPTER VI

### SUMMARY

1. Seven wheat varieties or selections were tested to determine the effect of different temperatures upon the incubation period and symptom severity of the yellow strain of the wheat streak-mosaic virus in wheat.
2. The incubation period decreased with an increase in temperature, between 22° C and 29° C.
3. The rate of development of symptom expression from mild to severe was more rapid at warmer temperatures than it was at cooler temperatures.
4. Lower temperatures (19° C) provided good growth of wheat but poor development of disease symptoms. Higher temperatures provided poor growth of wheat, together with poor development of disease symptoms.
5. The incubation period was shortest for field-susceptible varieties and longest for the field-resistant variety regardless of temperature. However, as the temperature was increased, the difference in incubation period was narrowed.
6. The development of symptom severity was more rapid in field-susceptible varieties than it was in field-resistant varieties, regardless of temperature. The difference, however, was again narrowed by higher temperatures.



7. The selection of the Triticum sp x Agropyron elongatum cross used in this study did not express resistance, if resistance is limited to the absence of symptoms or to a local lesion type reaction.

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