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THE HESSIAN FLY IN CALIFORNIA

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ECONOMIC IMPORTANCE

In California the Hessian fly (*Phytophaga destructor* Say) is of economic importance only in wheat-growing regions near the coast, where the influence of the ocean is sufficient to prevent extremely high summer temperatures. (Fig. 1.) Although the quantity of wheat grown in the valley portions of this region is being gradually reduced year by year, the many hilly sections now devoted to wheat will doubtless continue so indefinitely, because they are not well adapted for other crops requiring intensive cultivation and which otherwise might prove more profitable. Wheat is one of the most dependable and suitable of the few crops which the hill farmers can grow.

According to statistics for 1921, the last year for which figures are available by counties (*1*),[2] the annual value of wheat grown in the coastal counties where the fly occurs, or is likely to occur, is in the neighborhood of $3,500,000. To this must be added the value of the wheat cut green for hay, because the fly can reduce hay yield as

[1] The author desires to acknowledge his indebtedness to T. D. Urbahns, Margaret Marshall, B. G. Thompson, Percy Bartlam, and C. C. Wilson for much valued assistance in the course of the work reported in this bulletin. Helpful criticism of the manuscript has been received from W. B. Herms and W. R. Walton, and the material assistance of J. B. Hoyt and family, on whose ranch many of the observations and experiments were conducted, is especially appreciated.

[2] Numbers in italic in parentheses refer to "Literature cited," p. 25.

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well as grain yield. No separate statistics are available for wheat hay alone, the only figures given being for total grains cut green for that purpose. Since wheat is the favorite grain-hay crop it seems fair to estimate the annual value of wheat hay produced in the coastal counties as one-half of the total, or $5,500,000. An estimated total of $9,000,000 is, therefore, set as the value of the crop which the Hessian fly may affect.

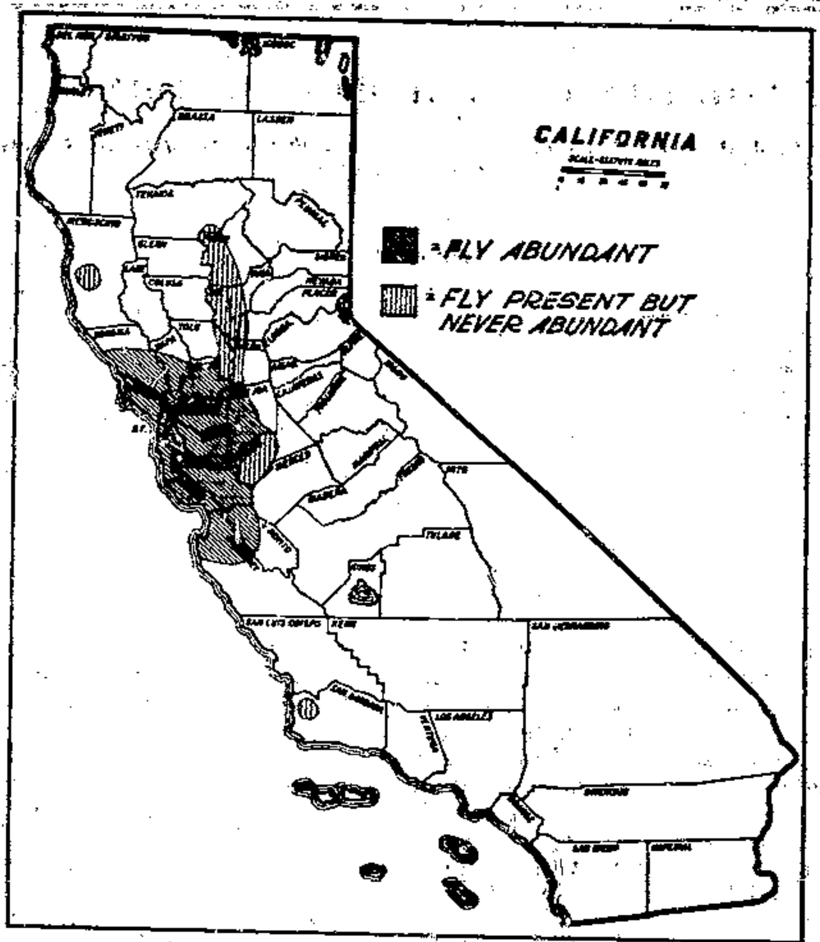

FIG. 1.—Known distribution of the Hessian fly in California

Just how much this insect does reduce the yield is very difficult to determine because of the variability in its abundance in different localities, in different fields, and even in different parts of the same field. Other factors also are involved, such as moisture and other meteorological conditions at critical times in the life histories of the insect and its host plant, together with variations in soil and cultural methods. It is abundant during practically every season in some localities within its range, and where it does occur in abundance it can not fail to cause injury, the character and degree of which will be discussed later, though the injury to the total crop liable to infestation is small. All things considered, a reduction of the crop by one-half of 1 per cent seems a conservative average estimate.

A reduction of one-half of 1 per cent on the basis of a $9,000,000 crop would amount to $45,000. A loss no greater than this is negligible, unless some cultural method of control can be found which would add nothing to the expense of growing the crop, and which in itself might increase the yield. On the other hand, a greater loss in the wheat crop appears to result during occasional years, as indicated by a study of the few California records published since 1879, by information obtained in talks with farmers, and by actual observation in the field. It therefore is desirable that a practical method of control be developed which the wheat grower may have at his command, even though this be needed only occasionally. Furthermore, when the study of the Hessian fly in California is considered as a phase of a national problem rather than as a purely local one, it assumes greater interest and potential value. May there not be some factor, such as parasitism, which keeps the fly under control in California, and which might be utilized to advantage in the Eastern States? May not a knowledge of the effects of the California climate on the life habits and distribution of the fly help to solve the problem of its control in regions where it is of greater economic importance? Such questions, at least, should be answered, in order to complete our knowledge and increase our ability to cope with the Hessian fly as a national entomological problem.

HISTORY

The Hessian fly has been present in California for many years, though, as in the case of its introduction into the eastern part of the United States, the means by which it first arrived probably never will be definitely known. Wheat has been grown in California since the first settlement, at San Diego in 1769, by the Franciscan missionaries, and it is possible that the fly may have been introduced from Spain by the original Spanish settlers, in wheat straw used for packing. It is fairly well established that the insect was present in Spain and in the island of Minorca early in the nineteenth century and had been there for many years previous to that time (*2, p. 318*). A study of the history of the Spanish occupation, however, has revealed no clues which would indicate the presence of the Hessian fly in California during that period. It may not have been introduced until after the influx of American settlers began in 1826, or even until the transcontinental railroad commenced operation in 1869.

The earliest authentic date of observation seems to have been 1879. Wickson (*11*) mentions this date in an interesting press article on the fly. Woodworth (*12, p. 312*) reported it so abundant in 1885 in experimental wheat plots in Berkeley "as to vitiate the culture and fertilizer experiments then under way." He also published observations extending from 1885 to 1889 on its abundance and on the relative susceptibility to fly injury of different varieties of wheat under test in plots during that time.

Agitation in wheat-growing and trading circles over the discovery of the Hessian fly in a field near Salinas City in 1899 moved Professor Wickson to write the article already referred to, in which he states that the Hessian fly was definitely known to have been present in California since 1879. In those days wheat was one of the most important export products of the State, and anything affecting this crop affected a considerable portion of the population, rural and urban, from the farmers to the crews of the clipper ships which carried it abroad. Professor Wickson's brief but excellent article apparently was designed to allay the fears, in the minds of many, that the Hessian fly was newly established in the region and was threatening one of the main sources of income.

A note on the Hessian fly by Riley (*9, p. 131*), in the first volume of Insect Life (1888) reads, "For a long time it was unknown on the Pacific coast, but during the past three years it has been quite injurious in parts of California." Koebele (*5*) contributed a note to Insect Life in 1890, in which he says, "This insect has been reported as being very abundant during spring (1889) in the central part of the State, destroying most of the wheat around Mount Eden." Then he continues with some interesting field and rearing notes, mentioning parasites.

Again, in 1891 Riley and Howard (*10*) record the receipt of puparia and adults from Mr. Koebele, who collected and reared them from several species of wild grasses. They compared these specimens carefully with the eastern form and concluded that they were identical.

The attention of farmers seems to have been attracted by serious Hessian-fly injury in 1895 and again in 1899. Notes by Theodore Pergande in the files of the Bureau of Entomology record the receipt in Washington, one in each of these years, of wheat and barley infested by *(Cecidomyia) Phytophaga destructor* from two California correspondents who wrote of serious injury to the wheat crop in their localities. Apparently no further complaints of the fly in California were received by the Bureau of Entomology until 1915, when a report of its abundance in wheat in Solano County, together with a request for advice, was received from the county farm adviser, J. W. Mills. T. D. Urbahns, of the bureau, verified the report and concluded that an investigation of the California phase of this insect was advisable. The author was detailed to the problem in 1916 and has followed it, with some interruptions, ever since.

SEASONAL HISTORY

The Hessian fly passes the long, dry California summer and fall as a puparium containing a quiescent larva (fig. 2), in the stubble and straw of the grain in which the larva matured during the previous spring. The puparia, or "flaxseeds," as they are commonly called, remain during the summer in the identical location in the stubble and straw that the young larvae occupied while sucking their food from the growing stems. Practically all Hessian flies infesting young wheat originate from the stubble of the previous season's wheat crop. Barley, and perhaps to a slight extent certain wild grasses, may be a minor source of flies.

Pupation of the larvae which have aestivated in their puparia is induced by the fall and winter rains. The time of the main pupation and the time of the emergence of the flies from the stubble depend upon the rainfall and temperature of the particular season. The main emergence usually begins in late February and continues

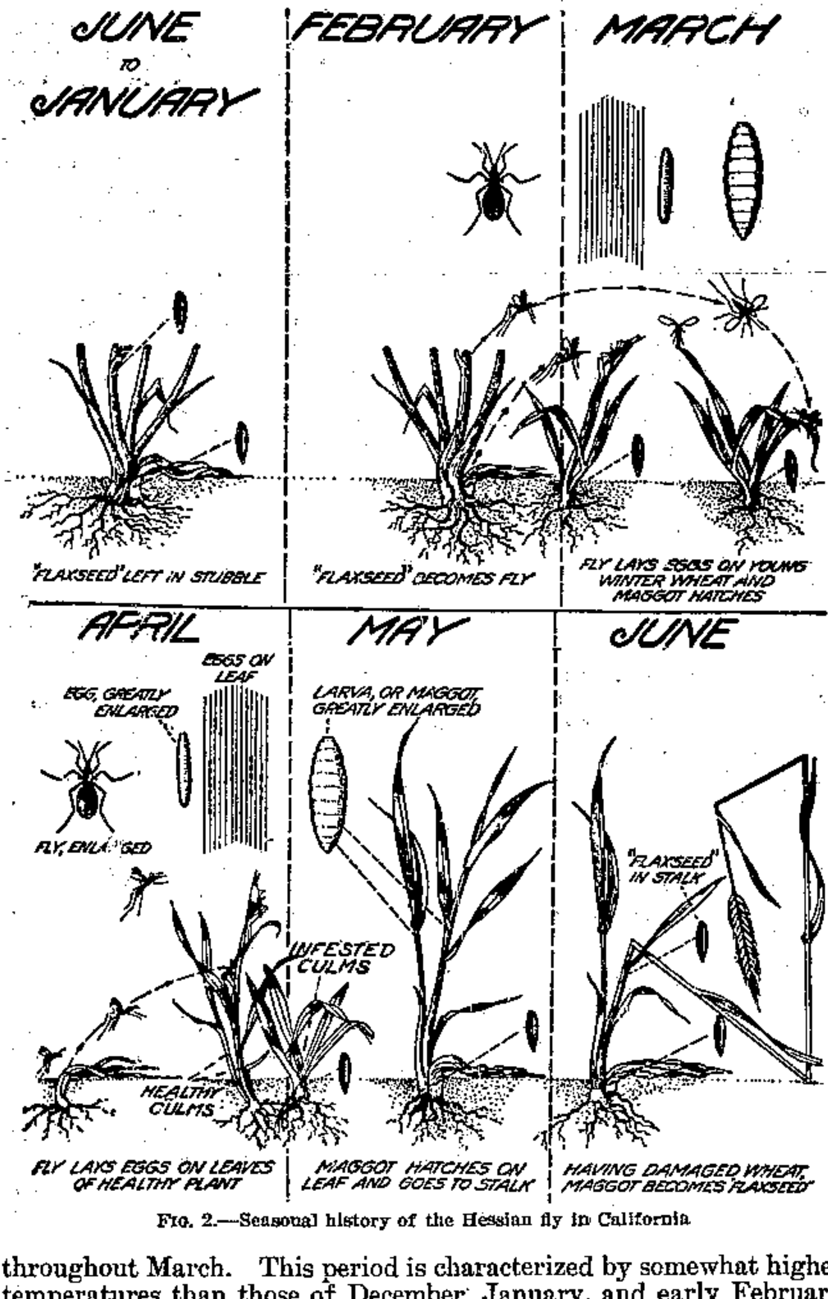

FIG. 2.—Seasonal history of the Hessian fly in California

throughout March. This period is characterized by somewhat higher temperatures than those of December, January, and early February and an abundance of moisture either from earlier or current rains.

There is no sudden, closely bunched emergence of all the adults during a limited period of a week or 10 days, such as that reported to occur in the fall in the Eastern States. Observations extending through eight seasons clearly indicate that abundant moisture is necessary to cause general pupation, and that in addition the average temperature must be above 45° F. In ordinary seasons, when abundant rains do not occur before December, even though there may be heavy rains later, the average temperature becomes too low for pupation by the time there is sufficient moisture to stimulate activity. Pupation does not then occur to any extent until the average temperature rises from the 45° to 50° average of December and January to the 50°, or higher, average of late February and March. Occasional individuals may pupate earlier in warmer exposures, or during short periods of warmer weather, and emerge as adults; and sometimes a few eggs may be found on young wheat. The prevailing low temperatures, however, seem to prevent the development of larvae from these eggs and also to check the growth of the wheat.

When the main emergence of adults from stubble in early spring occurs, the infestation of the young wheat of the current season is begun. Oviposition commences in February, becomes heaviest in March, and extends into April. By late March the earliest individuals of the new generation begin to form puparia in the young wheat. This first generation develops under the leaf sheaths at the bases of the stems, before the wheat has begun to form joints, and usually is the main brood of the year. A certain proportion of these, varying in different years, pupate at once and begin emerging as adults by the latter part of April. Usually, however, the larger part of the first brood in the young wheat become quiescent larvae inside their puparia and remain so throughout the following summer and fall. Those which do pupate at once emerge as adults during late April and early May, and give rise to a minor second generation in the same wheat. This generation develops into the puparia to be found at the joints of the stems, as all of the wheat is beginning to joint by late April. Practically all of the individuals of this second generation have formed puparia by the end of May, when the dry summer season has set in, and the activity of the Hessian fly ceases until the rains of the following winter.

Unusual conditions, however, may cause variations in the seasonal development of the fly. Some abnormally early pupation is often induced during the winter months by rainy periods accompanied by mild temperatures. Heavy rain early in the fall, before winter temperatures prevail, may also cause general pupation. Such an instance occurred in the fall of 1918, when 6 inches of rail fell during September 12–14, this being followed by several weeks of high humidity and mild temperatures. Pupation began at once, and most of the flies which had aestivated in the stubble since the previous spring emerged during late September and throughout October. The same rain which roused the flies to activity caused vigorous growth of volunteer wheat. This immediately became very heavily infested with the new progeny from the out-of-season adults. These larvae matured to the puparial stage before cold weather, and, since no cultivated wheat had been planted at the time of the abnormal fall emergence of flies, this extra brood in the volunteer wheat served to carry the species over the inactive winter period. The customary emergence of adults took place the following February and March, the adults coming mostly from the fall brood in the volunteer wheat instead of from the puparia in the stubble of the previous year's crop as is usually the case.

A third variation in seasonal history is the effect of rains and humidity in late spring. In April, 1925, rainfall and humidity were considerably above normal, causing the pupation and emergence of an unusually high proportion of the first brood of flies in the young wheat during late April and early May and the development of an abnormally large second brood at the joints of the culms. As a result, a majority of the aestivating puparia surviving the summer of 1925 in the stubble were located at the joints rather than at the bases of the stems. Under such a condition the burning of stubble should be more effective than usual in reducing the number of flies emerging the following spring to infest the new crop.

Incident to the location of most of the aestivating puparia at the joints, parasitism became unusually high during the summer of 1925, *Eupelmus allynii* being especially noticeable. Evidently the puparia at the joints are more accessible to ovipositing parasites than are those at the stem bases below the surface of the soil.

CHARACTER OF INJURY

Injury to the plant is caused only by the feeding of the larva. After hatching from the egg, which is deposited on the upper surface of a leaf blade, the larva crawls down the blade and underneath the leaf sheath. When it has reached a position near the junction of the leaf sheath and the stem it begins feeding by sucking the sap from the stem. It does not move about after feeding has begun, but forms its puparium without changing location. Culms which become infested while small cease to grow, assume an easily recognizable, characteristic appearance, and eventually die. The attack of a single larva is sufficient to cause the death of a small culm; although usually the adult lays several eggs on a single blade and several larvae mature coincidently in the same stem. Older stems which have begun to form joints by the time infestation takes place usually complete their growth and mature seed.

The degree of injury caused by the first or main generation, which attacks the wheat while it is still small, is difficult to determine. The actual reduction of the yield is not in direct proportion to the percentage of culms killed. A résumé of many field examinations indicates that a large portion of the culms would die for lack of moisture if they were not killed by the fly. In California wheat ordinarily sends up many more culms than are able to mature, and it seems to be largely a question of whether the surplus culms will succumb to the fly or to drought. An infestation occurring in 1923 will serve as an illustration. Examinations were made in a field of young wheat at points 100 yards apart on a line extending directly into the young wheat from the adjacent stubble field which was the source of infestation. One hundred culms were examined at each point with the results shown in Table 1.

TABLE 1.—*Relation between degree of Hessian-fly infestation in young wheat and drought injury, Birds Landing, Calif., 1923*

Distance from source of infestation	Culms matured or killed by Harmolita grandis			Culms died from drought or killed by the fly		
	Matured	Killed by Harmolita grandis	Total	Died from drought	Killed by the fly	Total
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
30 yards	34	20	54	8	38	46
100 yards	48	0	48	28	24	52
200 yards	48	0	48	40	12	52
300 yards	58	0	58	40	2	42

These results lead to the inference that even in the almost total absence of the fly the effect of drought alone is about the same as the combined effect of the first brood of the fly and drought where the fly is abundant. For the purpose of comparing fly injury in the different spots, it seems permissible to combine the culms killed by other insects with the matured uninfested culms. The totals thus obtained are fairly constant. In other words, whether 38 per cent of the culms are killed by the Hessian fly or only 2 per cent, the number of culms matured by the plants remains nearly the same. In the second part of the table it will be seen also that the total number of culms killed is nearly constant, whether the cause of death is the Hessian fly or drought.

Although the situation just described is fairly typical of ordinary years, it can not be assumed that injury by the first generation of the fly is always negligible. A season, or a series of seasons, particularly favorable to the insect might permit the infestation to increase to the point where the number of culms killed would be greater than the number killed by drought in the absence of fly infestation, though such an occurrence has never been observed. A very heavy infestation occurred in 1920 in the Montezuma Hills district near Rio Vista. In one field in this district two men were obliged to hunt diligently for two whole days to obtain two wheat plants free from the Hessian fly. The counts of 100 culms each, given in Table 2, show the degree of injury prevalent throughout the 200-acre field. The fact that the infestation in 1920 was unusually heavy is clearly shown by comparing Table 2 with Table 1, an example of a more typical infestation which occurred in 1923. It seems clear from these and other observations that the Hessian fly was decidedly more abundant and infestation by it more general in 1920 than usual.

TABLE 2.—*Degree of injury from a heavy infestation of the Hessian fly prevalent in a 200-acre field, Birds Landing, Calif., 1920*

Lots of 100 culms each	Culms not infested, matured	Culms not infested, died from drought	Culms killed by fly	Culms infested, but matured
	Per cent	*Per cent*	*Per cent*	*Per cent*
No. 1	18	10	48	24
No. 2	22	14	44	20

Even in this instance it is doubtful whether the first brood actually killed a greater number of culms than would have succumbed to drought in the absence of fly infestation. As shown in Table 2, 10 per cent or more of the culms were killed by drought in addition to those killed by the fly. This fact would indicate that the first brood did not prune the plants quite to the point where there would be sufficient moisture to mature all the uninfested culms, and also that the fly-killed culms would have been drought-killed if the fly had not been present.

There are at least two ways, however, by which the first brood of flies may reduce the crop—directly, by infesting all culms of some plants and preventing any of them from maturing, and, indirectly, by becoming the source of an abundant second brood in the same wheat. Scattered plants killed entirely by first-brood flies may be seen in heavily infested spots nearly every year. This loss is largely offset by the common custom of heavy seeding to allow for loss of plants in various ways. At the same time the farmer who seeds heavily for this purpose suffers a loss at least equal to the value of the extra seed used. The first brood is of indirect importance because the size of the second generation, which does definitely reduce the crop, depends on the magnitude of the first, from which it originates. Thus, indirectly, the first brood becomes a source of ultimate injury to the crop, the degree of which depends on the size of the first brood of emerging adults and this in turn is subject to the meteorological factors which control the amount of spring emergence of flies from the first-brood puparia.

The injury resulting from the flies of the second generation and the later stragglers of the first generation is more readily determined. It is of two types: (1) Reduction in the weight of grain produced by infested culms, and (2) breaking over or lodging of mature stems at the point where they have been weakened by the invading larvae.

Stems infested at joints ordinarily succeed in maturing. The writer has not attempted to determine the reduction in yield caused by this type of infestation. The figures given by Hill and Smith (*4, p. 72*) on this point indicate an average loss under Pennsylvania conditions of about 25 per cent in weight of grain in culms infested at joints as compared with grain in uninfested culms. In the fly-infested districts of California the proportion of maturing culms infested in this manner varies greatly, the average being about 30 per cent and the maximum observed 63 per cent. Assuming that the effect, on the yield, of larvae developing in joints is as great in California as in Pennsylvania, the crop as a whole would be reduced 7.5 per cent, or in the neighborhood of 2 bushels per acre, by this type of injury if 30 per cent of the culms sustained a loss of 25 per cent in weight of grain. At the same rate the maximum observed infestation of matured culms would result in a crop reduction of 15.75 per cent, or approximately 4 bushels per acre.

The breaking over of straw causes some loss of grain at harvest, though grain so lost is recovered as feed by grazing stock, either in the form of grain or in that of pasture after the grain has sprouted. As shown in Table 3, data indicating the quantity of grain lost through the breaking over of straw were obtained in 1924. From general observations it is the belief of the author that the lowest of these figures (that for area No. 1) represents rather more than the average loss from this source. Only those heads were counted which were so close to the ground that they, presumably, could not be collected by the harvester.

TABLE 3.—*Loss of wheat because of fallen heads resulting from Hessian fly injury, Birds Landing, Calif., 1924*

Areas of 1 square yard	Fallen heads	Weight of grain from heads	Loss per acre
	Number	*Grains*	*Pounds*
No. 1	14	93	64
No. 2	14	119	82
No. 3	21	158	109
No. 4	48	362	250

Thus there are three ways by which the Hessian fly may reduce the yield of wheat: (1) By killing young culms or entire plants early in the season; (2) by reducing the weight of grain in culms infested at the joints (although having completed their growth); (3) by loss of grain in heads that fall below the level at which they can be picked up by the harvester. The total loss from all these sources appears to be of no great consequence in ordinary years, but in seasons particularly favorable to the fly the crop may be greatly reduced by this insect.

DEVELOPMENT

The developmental stages of *Phytophaga destructor* have been fully described by a number of writers, particularly by McColloch (*6*), whose studies were made in Kansas. It seems unnecessary to repeat these descriptions in detail, since observations under California conditions indicate that the stages are the same as in the Eastern and Middle Western States. It may be of value, however, to record such supplementary and corroborative observations as have been made during the course of the present study.

THE EGG

The incubation period of the egg was observed in California to be from 6 to 12 days with the temperature averaging from 50° to 56° F., as shown in Table 4.

TABLE 4.—*Incubation period of the Hessian fly at Berkeley, Calif., in 1919*

Number observed	Environment	Date laid	Date hatched	Average temperature	Incubation period
				°*F*	*Days*
28	Potted plants in outdoor shelter	Feb. 7	Feb. 17–19	50	10–12
6 [1]	Not stated, probably same as above	Apr. 18	Apr. 24	56	6
102 [1]	do	do	Apr. 25	56	7
33 [1]	do	do	Apr. 26	56	8

[1] Observed by M. C. Lane.

The temperatures recorded in Table 4 are the monthly averages as given in the reports of the University of California weather station located about 300 yards from the laboratory, and serve only to give a general idea of the prevailing temperatures during the time these observations were made. A study of the weather records, however, reveals that the average temperatures during the incubation periods must have been approximately the same as for the entire month. The temperatures in the open-air shelter containing the cages were probably somewhat higher than those given in the table.

That this insect does not reproduce parthenogenetically might be inferred from the following observations: Of two unmated females observed, one laid a few eggs on a young wheat plant whereas the other did not, although ovipositing in a vial shortly before she died. No larvae developed in either case, and the eggs finally became dry and shriveled. The fact that these flies did not oviposit readily might also be considered as evidence that parthenogenesis does not occur. Although the few observations noted in this paragraph can not be considered at all conclusive, they certainly suggest the absence of parthenogenesis in this species and may serve to substantiate evidence from other sources.

The time of day when the eggs hatch was observed in a few instances on potted plants in an unheated room. In every case hatching occurred between the hours of 5 p. m. and 8 a. m. These and other more general observations would indicate that the larvae normally hatch from the egg and make their way underneath the leaf sheaths during the cooler parts of the day or during the night.

THE LARVA

Two newly emerged larvae were observed in the laboratory while making their way down the leaf and under the sheath. Both made this journey during the earlier part of the night. One larva emerged at 8.30 p. m. and spent 4¼ hours in crawling a distance of 15 millimeters to, and underneath, the ligule where the leaf blade joins the sheath. For more than half of this period the larva was motionless; during this time it might have been feeding, although this seemed very doubtful. The actual time consumed in crawling was only 1 hour and 35 minutes, the distances covered between rests ranging from 3 to 6 millimeters. The movements were sluggish, as will be seen from the fact that when the larva was most active it required 2 minutes to crawl 0.35 millimeter, a distance equal to its own length.

The other larva had emerged between 5 and 8.30 p. m. and had moved 3 millimeters down the leaf when first observed. Three and one-third hours more were required for this larva to crawl the remaining 12 millimeters to the ligule, surmount this obstacle, and disappear under the sheath. Both of these larvae followed one of the grooves in the leaf while crawling but sometimes crossed from one groove to another. Their rate of locomotion agrees substantially with that reported by McColloch and Yuasa (*8*).

The developmental period of the larvae has not been exactly determined. Field observations, however, show that the usual period from hatching to formation of puparium is from two to three weeks, which agrees with McColloch's findings in Kansas.

THE PUPA

The length of the pupal period is difficult to determine because the transformation occurs inside the puparium. The pupal period of 20 individuals was ascertained either by removing the larvae from their puparia or by opening the puparia just enough to see the larvae and placing them in small glass vials for observation. The mortality in puparia thus opened for observation was very high, but there seems to be no reason for believing that the observed pupal periods of those which survived were abnormal, when compared with those roughly determined by field observations.

A variable prepupal period of several days' duration was observed. During this period the cephalic end of the larva assumed a translucent, rounded appearance, after which the head and thorax finally formed, and the last larval skin, bearing the sternal spatula or "breastbone," was cast off. The average pupal period of 20 individuals was 22 days, with a range from 9 days during warm May weather to a maximum of 40 days during midwinter at Sacramento.

THE ADULT

In order to decide definitely the identity of the California species, a number of the adults, reared from wheat collected in several widely separated localities in the State, were submitted to E. P. Felt, who identified all of them as the true *Phytophaga destructor* of Say.

Results of field observations indicate that the adult flies are active only on comparatively warm days when the wind movement is slight. On cold, windy days they have been found resting quietly close to the ground among straw litter. When active in young wheat, the ovipositing adults fly among the plants in short, steady, rather rapid flights. They do not oviposit indiscriminately but usually favor the new tender leaves and smaller culms. When a female alights on a leaf blade she quickly crawls to the upper surface, faces toward the tip, lays a few eggs within a minute or less, and flies away. The eggs are placed end to end in short rows along grooves in the leaf surface. When a leaf upon which the female alights does not suit her fancy for oviposition she leaves almost immediately on another short flight.

The adults do not always stay close to the ground, however. During the spring of 1922 two boards, 10 feet long and 15 inches wide, were covered with a sticky material and erected at the edge of a stubble field from which Hessian flies were emerging. Females were caught at all heights on these boards up to 9 feet from the ground. It is therefore evident that they often rise some little distance from the vegetation. That no males were caught on the boards may be an indication that they do not migrate. Possibly they are held in the stubble by the attraction of newly emerging females.

The distance traveled by the flies evidently depends on their proximity to food plants, meteorological conditions, topography, and obstacles, such as dense woods or waste lands, encountered. Since it is the custom in California to plant wheat on clean summer-fallow, the source of infestation in a field is nearly always stubble in some neighboring field. The relation between the outside source of the flies and the extent and intensity of infestation in young wheat planted on summer-fallow, therefore, can be traced fairly well. As would be expected, the results of many field examinations show that infestation in a field of young wheat decreases steadily as the distance from the source of infestation increases. Table 1 (p. 8) serves as an illustration. It will be seen from this table that the percentage of infested culms decreased from 38 at a point 30 yards from the source of infestation to 2 at a point 300 yards from the stubble. In another field which was becoming infested from stubble in the adjoining field, the percentage of culms bearing eggs was determined by examination of 100 culms at intervals on a line extending directly into the young wheat. The infestation dropped off steadily from 48 per cent adjacent to the stubble to 22 per cent at a point 100 paces into the young wheat and to less than 1 per cent at points approximately one-half mile from the stubble.

That the direction of the prevailing wind, during the period when flies are abroad, evidently influences the direction and distance of their migration is indicated definitely by the results of a survey of 14 fields made in 1922 in the Montezuma Hills district. The prevailing wind in that locality is southwest. Where the flies had originated from stubble on the south or west sides of fields of young wheat, the infestation averaged heavier and extended farther into the field than was the case where the source of infestation was stubble on the north or east. Where variations occurred they could be plausibly accounted for by the effect of local modifying factors such as topography or windbreaks, and it seemed clear that the flies tended to drift with the wind.

FOOD PLANTS IN CALIFORNIA

Wheat is the favorite food plant of the Hessian fly, though it infests and matures successfully in barley and rye. Flies which apparently are identical with the true Hessian fly have also been reared from certain wild grasses. Although always very scarce, a careful search usually results in the finding of puparia in *Elymus triticoides* in California. Adults which expert dipterologists have been unable to distinguish definitely from the true *Phytophaga destructor* were reared from this grass, and the Hessian fly has been reared on *E. triticoides* at the Sacramento laboratory. Koebele (*5*) reported it to be present in several grasses in California in 1889, mentioning specifically *E. americanus* and *Agrostis* sp. So far as practical control of the pest in wheat is concerned, however, wild grasses are negligible as a source of infestation in this State, though they may serve as a perpetual reservoir to prevent extinction of the species where wheat is not grown. Neither does rye need further discussion, since it is not grown to any extent in the region where the fly occurs.

The relation between barley and the Hessian fly requires more consideration, since barley is the most important grain crop in California and the Hessian fly propagates readily in this grain. Material injury to barley by the fly is rare, however, only one seriously damaged field having been seen by the writer. In this case the barley was planted on wheat stubble which contained a great many live puparia from the previous season, and both cultural and meteorological conditions were very favorable to the development of the insect in the barley.

Given a choice, the fly will oviposit on wheat in preference to barley. One instance illustrating this point particularly well was observed in a field half of which was planted to barley and half to wheat. Counts in adjacent areas showed 21 out of 100 culms of the wheat infested, and 2 out of 100 culms of the barley infested. Other observations indicate that the light barley infestation was due to two factors: (1) Lighter oviposition on the barley, and (2) the less favorable character of this grain for successful development of the larval stages of the insect.

Barley is an important factor, nevertheless, in carrying the Hessian fly through a series of years when this crop is planted to the exclusion of wheat in a whole district, as in the lower Salinas Valley, where a light infestation of the fly is always present in it. Occasionally, however, some farmer will plant wheat for a year or two; and whenever this is done the rapid increase in intensity of fly infestation in this crop, as compared with that in the barley, is very striking.

Neither cultivated nor wild oats are ever attacked. Occasionally eggs may be found on the leaves of young oat plants, but no later stages of the fly have ever been discovered, either in the field or in the laboratory, where attempts have been made to rear the insect on oats.

PARASITES

Six species of parasites, all of them chalcidoids, have been reared from *Phytophaga destructor* in California, viz, *Merisus destructor* Say, *Eupelmus allynii* French, *Eupteromalus micropterus* Lind., *Pseuderimerus mayetiolae* Gahan, *Eutelus mayetiolae* Gahan, and *Calosota metallica* Gahan. The first three species named are common throughout the United States, but *P. mayetiolae* occurs only in California, and the last two occur only on the Pacific coast, so far as known. *P. mayetiolae*, *E. mayetiolae*, and *C. metallica* are new species reared in the course of the present work. All of the species oviposit in the puparia of the host during the spring and summer. From 5 to 50 per cent of the puparia are killed by parasites each year, the percentage varying considerably in different localities and different seasons. During the years 1916–1925 parasitism was not the dominant factor in limiting the abundance of the Hessian fly.

The distribution of the species of parasites is neither uniform nor constant. *Pseuderimerus mayetiolae* is by far the most important both in numbers and in distribution. *Merisus destructor* comes next in importance, being widely distributed throughout the infested area but rarely as abundant as *P. mayetiolae* and more variable in numbers. *Eupelmus allynii* is found commonly wherever the fly occurs and often is more numerous than *Merisus destructor*. *Eutelus mayetiolae* is the predominant parasite in the Salinas Valley and seems to be limited to that locality. *Calosota metallica* probably is primarily a parasite of the wheat straw worm, *Harmolita grandis* Riley, but was reared from the Hessian fly by M. C. Lane. It is rare as a parasite of the Hessian fly. *Eupteromalus micropterus* is also rare but has been reared from widely separated localities. The life histories of these parasites have been fairly well ascertained.

One of the most important parasites of the Hessian fly in the East is *Platygaster vernalis* Myers. This species does not occur in California so far as is known, and on account of its radically different habits might become a valuable addition to the species already present. In cooperation with W. H. Larrimer, in Indiana, 527 adults of *P. vernalis* were liberated at Birds Landing, Calif., in the spring of 1922. The conditions were favorable for oviposition by the parasite in the field where they were turned loose, and they set to work at once. During the following summer it was determined that the parasite had matured successfully in about 1 per cent of the host puparia, in the spot where the original adults were set free. Later in the season, however, all of the specimens found by dissection of puparia were dead.

In the fall wheat was again planted in the plot where the original adults of *P. vernalis* were liberated, in order to provide a convenient supply of Hessian flies for the parasite to attack the following spring, should any of them survive and emerge from the old wheat. A total of 2,843 puparia from this wheat were dissected during the summer of 1923, without finding any trace of *P. vernalis*. It seems likely, therefore, that no adults of this parasite emerged and oviposited in 1923. It is possible that *P. vernalis* has survived in very small numbers since its introduction in 1922, but this is doubtful because it has never been recovered in the dissection of thousands of puparia from the vicinity of the original liberation.

Other liberations of *P. vernalis*, totaling about 2,000 adults, were made in the spring of 1925. Field conditions were much less favorable than in 1923, however, for a successful introduction, and no progeny of these adults were discovered in host puparia collected during 1925 from the spot where the liberations were made.

METEOROLOGICAL CONTROL

EARLY SPRING MORTALITY

Periods of dry north wind often occur during the early spring when pupation and emergence of the flies are in progress. Such winds are noticeably detrimental to their activities. Emerging adults evidently can not travel and oviposit readily, on account of the velocity and drying effect of these winds. Newly hatched larvae occasionally have been found dead on the leaves, where they had become desiccated before they could reach shelter under the leaf sheath. Pupae in the stubble are also dried up and killed.

An instance of the killing of pupae in this manner was observed in the spring of 1924 in a field where dissections of 100 puparia were being made every fortnight. Before February 4 about 25 per cent of the puparia were alive and about 2 per cent contained dead pupae from the previous spring. Active pupation began in late February, and by March 1 most of the live puparia contained pupae. Three of the 100 puparia dissected on February 27 contained dead pupae. The next dissection, on March 14, showed an increase of 12 per cent in the number of puparia containing dead pupae, and this percentage held fairly constant throughout all later dissections. Several days of strong, dry, north wind occurred between February 27 and March 14, and the drying effect of this wind is thought to have been responsible for the mortality of the pupae, since similar records made in previous years show no such striking mortality at this season. The significance of such an occurrence will be seen when it is realized that only about 25 per cent of the total number of puparia in the stubble had survived the previous summer. As this 25 per cent was mostly in the pupal stage, the sudden increase of 10 per cent in dead pupae from the previous 2 per cent average to the later 12 per cent average must have been made at the expense of the 25 per cent total of puparia previously alive. Since 10 per cent is two-fifths of 25 per cent, it seems clear that the number of living puparia must have been reduced about two-fifths, or 40 per cent, through the desiccating effect of the wind.

SUMMER MORTALITY

The chief factors determining the regional and annual abundance of the Hessian fly are evidently the degrees of heat and humidity prevalent during the summer. It is impossible to determine from field observations how much individual effect each of these factors has on the welfare of the aestivating larvae inside their puparia. The fly is not present in any material numbers in the interior valleys, although its host plants are grown widely in these districts. In some places wheat and barley are grown throughout unbroken areas extending far into the interior from the coastal areas where the fly is abundant, and there is no apparent reason other than climatic factors to prevent this insect from spreading inland. In fact, a very slight infestation has been traced up the east side of the Sacramento Valley as far north as Chico. Since a few individuals have been able to survive the summer heat and drought in this region, the same thing may be true of the west side of the Sacramento Valley, the San Joaquin Valley, and the upper Salinas Valley. Rather extended search for the fly in these sections, however, has always resulted negatively, and one is forced to the conclusion that the Hessian fly is very rare or entirely absent in the interior regions, where the summer heat is not strongly modified by the direct cooling effect of the moist ocean winds.

From 25 to 75 per cent or more of the aestivating larvae become shriveled and dry inside their puparia every year, even in the districts more favorable to the fly, the percentage thus affected varying in different years and in different exposures. No cause other than simple desiccation by heat and drought has yet been connected with the death of these larvae. A notable instance of the desiccating effect of a sudden rise in temperature and decrease in humidity was observed in 1917 at Benicia. During the period from June 15 to 20 the temperature rose much above the previous maximum of 92° F. for the season at the Martinez laboratory, 5 miles away. Temperatures of 100° to 105° were recorded every day and were accompanied by very low humidity, the dew point being reached only once during the period. The effect of the sudden hot weather on the larvae in puparia was brought out strongly in data obtained by dissection of puparia taken from a field at Benicia periodically throughout the season. Repeated examinations of puparia in lots of 50 to 100, before the hot wave, showed approximately 80 per cent to contain living larvae; whereas similar dissections immediately afterward and at frequent intervals throughout the summer showed a sudden drop to approximately 20 per cent containing living larvae.

At the same time the percentage of puparia containing dry, shriveled larvae rose from none, before the period of extreme heat, to approximately 50 per cent immediately thereafter and throughout the summer.

ARTIFICIAL CONTROL

BURNING STUBBLE

The fact that stubble of the previous season's crop is the chief source of flies infesting young wheat leads at once to the assumption that burning the stubble before the flies have emerged will eliminate the pest. This conclusion is not borne out by field observations. In the first place, the stubble of wheat cut for grain is never all burned to the ground, and that of wheat cut for hay is too short to burn. Strips and patches which escape the fire, for one reason or another, are always present in burned-over fields. In the second place, repeated observations in such fields show that the majority of live puparia are not affected by the fire, because they usually are located in the plant crowns below the surface of the ground. Stubble does not burn below the soil surface even in the extremely dry fields of California. For example, in one burned-over field 100 plant-crowns of unburned stubble and 100 plant-crowns of stubble which had been burned to the ground were examined. The sample of unburned stubble contained 39 living puparia whereas the stubs of the burned plants contained 59 living puparia. To substantiate the result of this examination it may be stated that this field actually was the source of a heavy infestation in an adjacent field of young wheat the following spring. Of course, burning the stubble is of value to the extent that it destroys most of the puparia located at the joints; but hundreds of examinations show that in ordinary seasons live puparia are much more numerous in the plant crowns below the soil, where fire can not reach them, than they are in the aboveground portion of the stubble.

BURYING STUBBLE BY PLOWING

In the eastern part of the United States one of the principal control measures in use against the Hessian fly is the burying of stubble by summer plowing, to prevent emergence of the adults. In California, however, summer plowing is impracticable because of the hard, dry condition of the soil at that season. Not only is plowing difficult, but the lumpiness of the soil when plowed dry prevents thorough covering of the stubble. Another objection to plowing as a control method is the fact that this method of breaking the soil has been largely superseded in the fly-infested grain districts by shallow tillage with cultivators. The farmers have found this shallow type of cultivation better adapted to profitable grain raising on the prevalent heavy clay and adobe soils, under the present conditions of extensive farming and of limited labor supply.

Plowing down the stubble during the winter, after the first rains have moistened the soil and before the flies have emerged, no doubt would eliminate a considerable proportion of them. The rush of planting and of cultivating fields to be summer-fallowed, however, during the limited periods available between rains makes plowing at this time generally impracticable under the system of dry farming made necessary by the peculiar California conditions. Too many factors are involved to make a change advisable in the current farming methods for the sole purpose of combating the Hessian fly, as long as the injury from this insect remains at its present stage.

To gain some idea of the actual depth to which it is necessary to bury stubble to prevent emergence of the flies, puparia were buried at various depths under heavy soils in a series of flowerpots. In some pots the soil was left loose and in others it was packed. Some were kept moist and others were allowed to dry. Adults escaped readily through 3 inches of loose, moist soil and through 1 inch of tightly packed soil which had dried and cracked. The ability of flies to emerge through soil undoubtedly varies considerably with the depth, character, tilth, and degree of moisture. The experiment just cited, however, indicates that stubble containing puparia must be deeply and thoroughly buried in order to prevent emergence of adults.

The flies in the pots left the puparia and made their way to the surface of the soil in the pupal form. In nearly all cases where adults emerged in the pots their discarded pupal skins were found partly protruding from the soil; and when the soil was examined at the end of the experiments several dead pupae were found an inch or more from the puparia.

SUMMER CULTIVATION OF STUBBLE

In the course of dissections with other objects in view it was often observed that a higher proportion of puparia in the upper portion of the stubble were dried up than was the case with those down in the plant crowns below the ground. To obtain further information on the effect of dessication on the puparia, when the stubble is completely exposed to the open air, examinations were made in late summer and the percentage of live puparia in standing stubble was compared with the percentage alive in stubble which had been lying completely exposed on the surface of the ground. In all cases the percentage of live puparia in uprooted stubble was much lower than in standing stubble, and the percentage of dried-up larvae much higher. The records made in seven different fields are summarized in Table 5.

TABLE 5.—*Relative percentages of living puparia in standing and in uprooted stubble in seven fields in various localities in California in 1916, 1917, and 1920*

Locality	Year	Standing stubble			Uprooted stubble		
		Number of stubs examined	Containing live puparia	Containing dead puparia	Number of stubs examined	Containing live puparia	Containing dead puparia
			Per cent	*Per cent*		*Per cent*	*Per cent*
Altamont	1916	195	28	43	285	5	86
Do	1916	100	27	29	100	19	42
Do	1916	76	53	32	50	0	94
Do	1916	100	23	21	100	17	47
Rio Vista	1917	100	37	28	100	0	42
Benicia	1917	100	35	45	100	5	67
Birds Landing	1920	100	24	(1)	100	3	(1)

1 Not determined.

It will be seen that the counts in Table 5 show an average of only about one-fifth as many puparia surviving the summer in the uprooted stubble as in the standing stubble. This seemed a promising lead to a practical cultural method of control; therefore, during the summers of 1917 and 1918 four field experiments were carried out with disking and harrowing to throw the stubble out upon the surface in early summer. In 1917 practically all of the puparia were killed in the stubble which was completely uprooted and exposed. The method of cultivation, double-disking, failed to dislodge and throw out a considerable proportion of the stubble, however, and live puparia were common in this and the buried stubble. The trials in 1918 were less promising, and though there was a decidedly smaller proportion of live puparia in uprooted stubble than in standing stubble, the percentage killed was not sufficient to prove a practical control. This result was probably due to the comparatively low maximum temperature during the summer of 1918. At any rate, it was shown that summer heat and drought could not always be depended upon to kill a sufficiently high proportion of the puparia in exposed stubble to effect practical control.

It was learned from the experiments that the problem of thoroughly uprooting and exposing the stubble is not so simple as it would seem. Double-disking was not sufficient, nor was double-harrowing with spring-tooth harrow, which was tried on one plot. The best of the three methods tried was double-disking followed by spike-tooth harrowing, though this was not really satisfactory. Burning the stubble before the cultivation would have made the operation more effective. All of the information at hand leads to the belief that in most years the summer heat and drought would be effective in killing the puparia in uprooted stubble, and perhaps at some future time, under more intensive farming conditions, summer cultivation to kill the Hessian fly will be more practicable. At present, however, conditions do not warrant its general use, for the following reasons: (1) The difficulty, especially in heavy, hard-baked soils, of throwing all the stubble out on the surface with the implements now commonly at hand; (2) the possibility of failure of the weather to do its part; and (3) the likelihood that the cost of the operation would amount to more than the average annual loss caused by the fly.

SPRAYING STUBBLE TO KILL PUPARIA

Spraying stubble to kill the puparia therein doubtless would not be a profitable procedure under ordinary conditions, even if an effective chemical for the purpose were available. Circumstances under which spraying might be of practical value are not beyond the bounds of possibility, however, provided a cheap, easily obtained chemical possessing the necessary penetrating and killing qualities could be found. With this object in view samples of stubble containing puparia were sprayed with kerosene, coal-tar creosote, cresylic acid, and two widely used phenolic disinfectants. The samples were allowed to lie in the open air for six days and then were placed in cages for the emergence of adult flies. In every case more adults emerged from the sprayed lot than from the check lot of unsprayed stubble. Penetration of bare puparia by the chemicals was effected only by actual immersion for a day or more, and even after the chemicals had reached the inclosed larvae their effect appeared to be rather gradual. These particular chemicals, therefore, seem to be of no value for killing puparia in stubble.

EARLY PLANTING

The chief measure used in the eastern part of the United States to prevent Hessian-fly injury is to plant the wheat sufficiently late in the fall to escape the oviposition of the fall brood of flies emerging from stubble and volunteer wheat. In California late planting to escape Hessian fly injury is out of the question, because the main emergence of flies from the stubble does not usually occur until March. Wheat planted after that time would have slight chance of maturing a good crop for lack of moisture. Exactly the opposite procedure—that is, early planting and stimulation of early, vigorous growth—has been shown by experience to be the best practice for other reasons as well as for reducing Hessian-fly injury. As has been previously stated, the flies distinctly prefer to oviposit on the smaller, tenderer culms and leaves. Not only are large, strong plants more likely to be avoided by the ovipositing flies, but they are also better able to withstand and overcome fly injury.

ROTATION OF CROPS

Obviously, the farther from the source of flies wheat can be planted the less likely it is to become infested. The custom, already in vogue in California, of rotating wheat with summer-fallow and pasture is decidedly beneficial from the point of view of Hessian-fly control. Most of the wheat is now planted on summer-fallowed land. As a result, infestation must originate from outside the field and is less intense and widespread than in fields planted on wheat-stubble land. Where wheat follows wheat in the same field for consecutive years, fly injury is much more severe.

PLANTING RESISTANT VARIETIES

Since efficient control of the Hessian fly can not be effected economically in California by cultural methods or by destruction of puparia in the stubble, it is necessary to seek other means for a complete solution of the problem. The best possibility seems to be the development of resistant or immune varieties of wheat suitable to the region. Investigations with this purpose in view have been pursued during the last six years. There are four phases to the solution of the problem of immune varieties: (1) Testing the fly resistance of established varieties suited to the region, (2) testing the adaptability to the region of varieties known to be fly-resistant, (3) developing fly-resistant strains by selection from the varieties now commonly grown, (4) developing desirable fly-resisting varieties by crossing the commonly grown susceptible varieties with fly-resistant but otherwise less desirable varieties.

TESTING THE FLY RESISTANCE OF ESTABLISHED VARIETIES SUITED TO THE REGION

Seed was obtained of all the available wheat varieties which agronomists of the Bureau of Plant Industry of the United States

Department of Agriculture and the State experiment station considered at all suitable for commercial production in the fly-infested districts. Plots of these varieties, which are shown in Table 6, were planted in the field where they would be most exposed to heavy infestation. None of them possessed any greater resistance to fly injury or made any better yields than the wheats already in common use. The distinctly poorer varieties in yield and fly susceptibility were eliminated from the later tests. Infestation in the variety Onas was particularly intense and the test indicated this variety to be very susceptible to fly injury. The lighter infestations indicated in Table 6, for 1922 and 1923, were due to the generally less intense fly infestation in those years and not to any increased fly resistance in the wheats.

TABLE 6.—*Wheat varieties tested for resistance to the Hessian fly, Birds Landing, Calif., 1921–1923*

Variety	Per cent of plants infested			Variety	Per cent of plants infested		
	1921	1922	1923		1921	1922	1923
Baart	97	95	68	Illini Chief	11		
Big Club	100			Little Club	100	87	58
Bobs	100			Marquis	98	91	
Bunyip	95	79	58	Pacific Bluestem	100	81	63
"California Gem"	99			Prohibition	8	0	9
Cedar	99	80		Propo	100	77	
Colorado No. 50	99			Regenerated Defiance	100		
Dart	100	94	57	Sonora	89	83	
Dawson	3			Sunset	58	48	
Defiance	100	94	57	Turkey	78	26	
Early Defiance	77	50	43	White Federation	100	89	49
Hard Federation	100	87	47	Onas [1]	38		

[1] Test also in 1924.

TESTING THE ADAPTABILITY TO THE REGION OF VARIETIES KNOWN TO BE FLY-RESISTANT

Three varieties, Dawson, Illini Chief, and Prohibition, were included in the tests recorded in Table 6 because of their reputed resistance to the Hessian fly. They lived up to their reputation so far as fly resistance was concerned; but they are winter wheats, not at all suited to the environment, and yielded very poorly. Observations showed that the flies oviposited on these varieties even more abundantly than on the others, on account of their slow growth and small size during the oviposition period. Furthermore, the eggs hatched, and large members of the larvae successfully reached their normal feeding position under the leaf sheaths. Some internal character of the plants, not yet ascertained, prevented most of these larvae from maturing. Similar observations have been made by McColloch and Salmon (*7*) in Kansas on a number of resistant varieties. It is hoped that the specific factors rendering those and other varieties resistant or highly immune to attack can be discovered. With this object in view histological and microchemical studies for comparison of the anatomy of resistant and susceptible varieties have been made, but no positive results have yet been obtained. A knowledge of the characters involved would facilitate intelligent development of varieties possessing the desired immunity to the fly along with the other characters, such as high yield and quality, necessary to a commercially desirable wheat.

In 1924 seed was obtained of as many as possible of the varieties reported to be distinctly resistant to the Hessian fly. The objects in view were not only to test their adaptability to California conditions and their resistance to the fly but also to determine which fly-resistant varieties would be most suitable to cross with the wheats commonly grown in California, in order to produce new fly-resistant varieties better adapted to the region. The varieties used, except for Prohibition, were the ones reported by Haseman (3) and McColloch and Salmon (7), most of the seed being obtained through the courtesy of these gentlemen. The wheats were planted in rows in adjacent 3 by 6 foot plots on uniform soil and under identical conditions. Two seasons' results are summarized in Table 7.

TABLE 7.—*Relative infestation of different wheats by the Hessian fly at Birds Landing, Calif., in 1925 and 1926*

Variety	Crop year	Source of seed	Date planted	Puparia in 100 culms	Culms infested	Plants infested
				Number	*Per cent*	*Per cent*
Little Club (check)	1925	Common	Nov. 14, 1924	131	52	92
	1926	do	Dec. 16, 1925	358	75	100
Kanred	1925	California Experiment Station C. I. 5146.	Nov. 14, 1924	8	5	28
	1926	Progeny of same	Dec. 16, 1925	63	15	48
Mediterranean	1925	California Experiment Station C. I. 5303.	Nov. 14, 1924	0	0	6
	1926	Progeny of same	Dec. 18, 1925	45	10	18
Poole	1925	California Experiment Station C. I. 3488.	Nov. 14, 1924	46	23	61
Fulcaster	1925	California Experiment Station C. I. 4862.	do	0	0	8
	1926	Progeny of same	Dec. 16, 1925	21	5	16
Prohibition	1925	Descended from C. I. 4068, U. S. B. P. I. Chico, Calif.	Nov. 14, 1924	0	0	1
	1926	Progeny of same	Dec. 16, 1925	14	7	22
Pacific Bluestem (check)	1925	Descended from C. I. 3019, U. S. B. P. I. Chico, Calif.	Nov. 14, 1924	201	68	96
Dawson	1925	Kansas Experiment Station C. I. 3342.	do	0	0	2
	1926	Progeny of same	Dec. 16, 1925	23	6	8
Currell	1925	Kansas Experiment Station C. I. 2906.	Nov. 14, 1924	93	39	69
Illini Chief	1925	Kansas Experiment Station, Kans. No. 769.	do	5	4	12
	1926	Progeny of same	Dec. 16, 1925	28	10	55
"Dietz"	1925	Missouri Experiment Station W. 1426.	Jan. 13, 1925	274	55	99
"Ziegler's Choice"	1925	Missouri Experiment Station W. 112.	do	42	18	56
	1926	Progeny of same	Dec. 16, 1925	1	1	7
"Michigan Wonder"	1925	Missouri Experiment Station W. 29.	Jan. 13, 1925	19	12	63
	1926	Progeny of same	Dec. 16, 1925	25	9	16
Fulcaster	1925	Missouri Experiment Station W. 16.	Jan. 13, 1925	37	11	58
	1926	Progeny of same	Dec. 16, 1925	0	0	6
Little Club (check)	1925	Common	Jan. 13, 1925	242	67	94
	1926	do	Dec. 16, 1925	470	78	98

Exclusive of the check varieties, none of these wheats are suited to the region, being of winter habit and easily shattered, but all except "Dietz" showed decided resistance to the Hessian fly. Oviposition was heavy on all varieties, and fully as many larvae reached their normal feeding position in the resistant wheat as in the susceptible varieties. A very small proportion of the larvae made any appreciable growth, however, substantiating the evidence already cited that the resistant varieties possess some histological or biochemical peculiarity detrimental to the development of the larvae. This peculiarity can not be one rendering the varieties inherently unsuitable for the commercial production of good wheat, because several of them are now widely grown and highly favored in regions to which they are suited. Certain of these wheats appear to be distinctly more suitable than others for crossing with susceptible varieties. The tests are being continued.

DEVELOPING FLY-RESISTANT STRAINS BY SELECTION FROM THE VARIETIES NOW COMMONLY GROWN

In 1920 fly-free plants were located in fields where practically all of the plants were infested. As the infestation was extremely heavy, it was thought that some of the fly-free plants perhaps might possess a definite quality of immunity that could be fixed by selection. Descendants of these plants have been grown in separate plots according to their ancestry every year since that time. With the exception of the first year, when the seed was not separated by seeding in rows, and the second year, when only a few of the best head selections were so grown, the seed from individual heads has been planted in separate rows, called head rows, placed side by side about 6 inches apart in the plot. Each year, at harvest, seed is kept from only the best heads of the uninfested plants from the most lightly infested head rows. The descendants of most of the original field-selected plants did not develop any decidedly resistant qualities. Those of one fly-free plant from a field of Baart wheat, however, have shown not only a much higher percentage of fly-free plants but also a decidedly lower intensity of infestation than unselected wheat of the same variety grown under identical conditions in adjacent check plots. Table 8 will give an idea of the results obtained in this instance.

TABLE 8.—*Results of selection of Baart wheat for resistance to the Hessian fly, Birds Landing, Calif., 1921–1926*

PERCENTAGE OF PLANTS FREE FROM THE FLY

Crop year	Total number of plants	Per cent of plants fly free	Headrows (selected)			Check (unselected)	
			Total number	Per cent of plants fly free		Number of plants	Per cent of fly-free plants
				Lowest	Highest		
1921	200	22.5				100	3
1922	1,329	57	12	50	97	100	5
1923	3,642	92	72	73	100	200	30
1924	4,371	48	178	0	96	300	0.333
1925	1,285	78	71	50	100	300	6
1926	1,999	66	68	27	100	300	0.007

TABLE 8.—*Results of selection of Baart wheat for resistance to the Hessian fly, Birds Landing, Calif., 1921–1926*—Continued

INTENSITY OF INFESTATION

Crop year	Number of culms examined		Number of puparia per 100 culms		Number of puparia per infested culm	
	Selected	Unselected	Selected	Unselected	Selected	Unselected
1924	297	284	37	228	1.9	3.4
1925	400	300	12	174	1.6	3.0
1926	400	300	22	343	1.6	5.4

It is possible that some of the increased resistance of these plants is due to the greater vigor possessed by this strain. The evidence, however, indicates that there is some definite quality of resistance involved, because it has been observed, as in the case of the resistant varieties already discussed, that only a very small portion of the fly larvae makes any appreciable growth, although great numbers successfully reach their normal feeding position in the stems. Whatever the reason for the reduced infestation in this wheat, it is evident from the foregoing results that fly injury can be reduced materially by the process of selection.

DEVELOPING DESIRABLE FLY-RESISTANT VARIETIES BY CROSSING

The development of desirable fly-resistant varieties by crossing has not yet been attempted by the writer, but tests to determine the most desirable varieties for this work are now in progress.

In view of the fact that so many wheat varieties possess distinct fly-resistant qualities, it is surprising that so little effort has been made to determine the possibilities of resistant wheats as a means of eliminating the ravages of the Hessian fly. From the results recorded above, in addition to those reported by McColloch and Salmon (7) and others, two things seem apparent: (1) That several widely grown varieties of wheat do possess a definite inherent quality rendering them highly resistant to the Hessian fly; (2) that it may be possible to produce still better fly-resistant varieties by selection and breeding. The progress in selecting Baart for fly resistance, just described, is of course only a beginning; but if positive results can be achieved with one variety, why not with others? Furthermore, it seems probable that artificial crossing of resistant with desirable susceptible varieties under the guidance of expert plant breeders might lead to more striking and valuable results than selection alone.

SUMMARY

In California the Hessian fly is abundant only where the summer climate is distinctly affected by the modifying influence of the ocean. It injures the wheat crop to a slight extent practically every year and causes serious injury in occasional years when climatic conditions are particularly favorable to its development. It passes the summer, fall, and winter in the form of puparia in the stubble. The main emergence of adults from the stubble usually occurs in March, and

a minor emergence of adults from the young wheat in late April. Heavy September rains have been known to cause most of the flies to issue from the stubble in early fall. The injury to the wheat takes place during March, April, and May and is caused by the feeding of the larvae underneath the leaf sheaths. The life stages of the Hessian fly in California are identical with those found in the Eastern States.

Several hymenopterous parasites are present but do not control the insect. The artificial control methods used in the eastern part of the United States can not be applied in California because of the radically different climatic conditions. Burning stubble, plowing it under, and throwing it out upon the surface by cultivation in early summer to cause desiccation of the puparia, are partially effective control measures but are not universally applicable. The development of resistant varieties is only in the experimental stage but offers some possibilities. The most practical measures for control of the Hessian fly in California are practices already in common use for other reasons. These are rotation of crops, early planting, and the stimulation of rapid, vigorous growth.

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