THE LIFE-HISTORY OF THE POTATO TUBER MOTH *GNORIMOSCHEMA OPERCULELLA* (ZELLER) AND ITS CONTROL IN STORAGE

by

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ABSTRACT

The life history of the potato tuber moth Gnorimoschema operculella (Zell.) and its chemical control in storage have been studied in the present investigation. The period required for the development of one generation was found to vary inversely with temperature. In winter the period was found to vary between fifty and fity-nine days, while in summer it varied between twenty-four and thirty-three days. The optimum temperature for reproduction and egg-laying was found to be about 28 to 29°C. Under the prevailing weather conditions in Lebanon there is a possibility of having more than 7 to 8 generations a year.

For the control of the moth in storage three contact insecticides, DDT, Sevin and Lindane, have been used as water dilutions at two concentrations each, in which the empty bags of potatoes were impregnated. The treatments have been replicated three times. The three insecticides showed equal effectiveness in fully controlling all the moths, which resulted in 100 per cent protection of stored tubers.

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INTRODUCTION

Potato is a major field-crop in many parts of the world. The world-area planted in potatoes is about 24.8 million hectares, with an annual production of about 276 metric tons (FAO, 1960). In Lebanon, the area is about 4500 hectares, producing about 38000 metric tons of potatoes annually at a value of about L.L.3,360,000 (Lebanon, Minist. of Agric., 1960).

Among the many pests of field and stored potatoes the potato tuber moth Gnorimoschema operculella (Zeller) stands as a most serious one, especially on stored potatoes, almost all over the world. Yet, it was not recorded from this country until very recently when Talhouk (1961) reported it for the first time from Lebanon and Syria as a serious pest on potato.

Since that record, nothing has appeared in the literature dealing with its life-history or control measures in this country. Thus, it was found worthwhile to study its life-history and its control measures on potatoes in storage.

PART I

LIFE HISTORY

REVIEW OF LITERATURE

Taxonomic Position

The potato tuber moth, *Gnorimoschema operculella* (Zell.) belongs to the Lepidopteran family Gelechiidae, a family of about 400 genera and 4000 species, mostly of small moths, distributed all over the world (Imms, 1957).

Formerly, this moth was known as *Phthorimaea operculella* Zell. until Busck (1931) proved that the genus *Phthorimaea* was synonymous with the genus *Gnorimoschema*, a finding that was later confirmed by Mendes (1938). By 1939, the name *Gnorimoschema operculella* (Zell.) was finally adopted, and the previous name *Phthorimaea operculella* Zell. was used only as a synonym (De Nardo, 1939).

Distribution and Hosts

Gnorimoschema operculella (Zell.) is believed to be of Central American origin (Whitehead *et.al.*, 1953). Now it is distributed almost all over the world.

Its spread was facilitated by the increased exportation and importation of potatoes from country to country. It is reported from South Europe, North Africa, the Mediterranean Islands, India, Pakistan, Burma, Indonesia, the whole of Australia, Tasmania, New Zealand, the Pacific Islands, North and South America and the West Indies (Yugoslavia, Official Gazette, 1935; C.I.E. Dist. Maps, 1951).

Records of this pest in the Middle East are relatively recent. It was first recorded from Cyprus in 1918 (Crop Pest Campaigns, 1920). From Egypt it was reported as a serious pest of potato in 1939 (Attia and Mattar, 1939); while from Palestine it was reported only in 1943 (Mason, 1943). From Lebanon and Syria, it was Talhouk (1961) who reported it for the first time.

The list of hosts includes field and stored potatoes, tomato, egg-plant, pepper, tobacco (on which it is known as the tobacco split worm), and other solanaceous plants (C.I.E., Dist. Maps, 1951).

Life History

Very few studies appear in the literature dealing with the life history and development of G. operculella (Zell.), and most of these are part of control-measure studies.

The female starts egg-laying within 24 to 48 hours after emergence. Eggs are laid in cracks and pits on the tuber (Lloyd, 1943-44). A single female lays a total of 30 to 80 fertilized eggs (Bartoloni, 1951). Dutt (1914) reported 100 to 150 eggs per female, while Whitehead et.al. (1953) reported as much as 300 eggs per female. Picard (1913) gave evidence of parthenogenesis in about 9 per cent of the females, which resulted in a progeny of about equal numbers of males and females.

The incubation period varies with temperature; it takes four days in July, 15 to 17 days in October, and 29 days in November through December (Bartoloni, 1951). No hatching and, apparently, no larval growth take place below 50°F (Picard, 1912).

The larva hatches from the egg and starts feeding by digging superficial tunnels just beneath the skin. These tunnels are outlined as irregular

channels by the sinking of the discolored skin covering them (Whitehead et.al., 1953). As the larva grows it digs deeper and deeper into the tuber, and seals the tunnels with fecal matter. Langford (1934) reported that newly-hatched larvae could be kept without food for 13 days at 15 to 50°F, and when transferred to room temperature they could complete their development. The duration of larval period also varies inversely with temperature. According to Bartoloni (1951) it takes only 14 days to be completed in summer, and 68 to 97 days in November through March (in Italy); while Metcalf et.al. (1962) reported the duration to be 14 to 21 days under conditions in the United States. According to Langford (1934), 16 per cent of fully-grown larvae survived exposure to above-freezing temperatures (35 to 40°F) for five months, and reached the adult stage.

When the larva is fully mature it pupates either outside the tuber or inside of it (Metcalf et.al., 1962). The duration of the pupal stage varies also with temperature. According to Metcalf et.al. (1962) it takes seven to ten days to be completed; while Bartoloni (1951) reported its length to be only four days in July, and 36 to 97 days in

November through March. The moths overwinter in the field in the pupal stage (Underhill, 1926) despite the fact that only about 1.6 per cent of them can survive exposure to 35 to 40°F for five months and reach the adult stage. However, 60 to 70 per cent of the pupae can tolerate slightly-higher temperatures (40 to 48°F) for 60 days and still reach the adult stage (Langford, 1934).

At the end of pupation the adult moths emerge from their cocoons, mate within 24 to 48 hours after emergence, the females lay their eggs about 48 hours later and die a few days after they complete egg-laying (Lloyd, 1943-44). Unfertilized females live longer than the fertilized ones (Attia and Mattar, 1939).

The duration of the life-cycle varies with temperature. According to Bartoloni (1951) it requires 26 to 28 days in summer and as long as 140 days in winter. Newman (1920) reported it to require 41 to 62 days in summer and 92 to 125 days in winter in West Australia under laboratory conditions. In warm countries it lasts for 17 to 18 days in summer and a maximum of 54 days in winter under laboratory condi-

tions (Dutt, 1914). Because of this variation the number of generations per year varies from country to country. While Newman (1920) reports only six generations a year in West Australia, Dutt (1914) reports as much as 14 generations a year in India.

In general, hot, dry years favor the development of the moth (Metcalf et.al., 1962); a finding which is based on a calculation of the number of day-degrees required for its development (Langford and Cory, 1932).

MATERIALS AND METHODS

A stock culture of G. operculella (Zell.) was secured from three infested tubers kept in a refrigerator for two months at about 10°C. When the experiment was started the pests were in the mature larval stage. On November 9, 1962 the tubers were transferred to transparent plastic boxes in order to watch for the emergence of the adults. Each box measured 22.5 x 13.5 x 8 cm. and contained two circular windows, one on each of its opposite narrow sides. Each window was 3.0 cm. in diameter and was covered by a nylon gauze of fine mesh which allowed free aeration but prevented the escape of moths or the invasion by other insects from outside.

Directly after the emergence of the moths they were transferred to breeding cages where clean tubers were introduced to receive eggs. Each cage measured 28 x 28 x 36 cm.; its frame and bottom were made of wood. Two adjacent sides were made of muslin sheets to allow free aeration; the top, the third side, and half of the fourth side were made of transparent

plastic sheets to allow free inspection. The other half of the fourth side, measuring 14 x 36 cm. high, was left as an entrance and was covered from its four sides by a white cloth sleeve, measuring 48 x 45 cm., open at both ends. This sleeve served to guard against escape of the moths while introducing or removing material from the cages.

One to two days after introducing the clean tubers into the cages they were examined for eggs under a binocular microscope, removed to a plastic box of the type described above and a new set of clean tubers was introduced into the cages for further oviposition.

For studying development at low temperatures and constant humidities Zwolfer constant-humidity chambers were used. The chamber measured 6.0 cm. in diameter and 3.0 cm. high. Saturated solutions of sodium chloride (NaCl) and barium chloride ($BaCl_2$) in the chambers maintained 75.3 per cent and 90.2 per cent relative humidities respectively. Slices of potatoes with eggs on them were introduced into the chambers, and the covers were sealed with vaseline. The chambers, with their contents, were kept in a

refrigerator at a constant temperature of 10°C from March 9, 1963 to May 31, 1963, i.e., for eighty-four days.

Freshly-cut tubers and a 10 per cent sugar solution served as a source of food for the adults.

Eggs were measured with an occular micrometer scaled down to 0.01 mm.

The laboratory temperature was recorded at the time of observation from a small mercury thermometer.

The relative humidity was recorded at the time of observation from readings taken from a wall metallic Haar hygrometer.

RESULTS AND DISCUSSION

A. RESULTS

I. General Morphology

Egg (Fig. 1)

The oval egg is pearly white when laid. Later, it turns blue to dark-blue a day before hatching. It is very soft and fragile. The average dimensions are 0.51 x 0.36 mm. (Table I).

Larva (Fig. 2)

The larva is of the eruciform type. When newly-hatched it is white in color except for the black epicranial plates, clypeus, labrum, and the prothoracic shield. It measures about 1.6 to 1.8 mm. in length. The mature larva is violet to green in color except for the black epicranial plates, clypeus, labrum, the prothoracic shield, and the black thoracic legs. It measures about 9 to 13 mm. in length.

TABLE I

LENGTH AND WIDTH MEASUREMENT OF EGGS OF G. OPERCULELLA (ZELL.)

Egg	Dimensions in mm.	
	Length	Width
1	0.528	0.396
2	0.495	0.363
3	0.528	0.330
4	0.495	0.363
5	0.495	0.330
6	0.528	0.363
7	0.528	0.363
8	0.495	0.363
9	0.495	0.330
10	0.495	0.363
Average	0.508	0.356

Pupa (Fig. 3)

The pupa is of the obtect type. At first it is light brown in color, then turns to dark-chocolate brown one day before the emergence of the adult. It measures about 7 mm. in length and 2 mm. in width at the region of the body which is the widest.

Adult (Fig. 4 and 5)

Both males and females have cryptic light brown coloration of the body and wings. However, the males are characterized by having the fore wings mottled with small scattered dots. The females are characterized by having the black dots on the fore wing more concentrated and grouped together so that on repose they are seen by the naked eye as one big x-shaped dot joining the right and left fore-wings (Fig. 4) The males also differ from the females by having two spiny and long claspers at the hairy tip of the abdomen, while the females have the tip of the abdomen less hairy and devoid of claspers (Fig.5).

Both males and females are equal in size. Those of the winter generations measure an average of 8 mm. from head to the tip of the abdomen, with

a wing expansion of 14 mm. Moths of the summer generations are slightly smaller; the males being 6 mm. long and the females 7 mm. long.

II. Life History

Eleven moths emerged from the three infested tubers between November 14 and 24th, 1962 at a room temperature of 25 to 26°C and a relative humidity of 57 to 84 per cent. There is no obvious reason for such a fluctuation in the relative humidity. The females laid eggs on the same tubers and died between November 24 and December 7, 1962.

Adults of the first generation emerged between January 3 and 25th, 1963. They actively fed from freshly-cut tubers and from a 10 per cent sugar solution.

In winter the eggs hatched within an average period of 99 days at 18 to 21°C and 72 to 85 per cent R.H., while in summer they hatched within a period of 4.7 days at 31 to 32°C and 77 to 85 per cent R.H. (Table II).

TABLE II

INCUBATION PERIOD REQUIRED FOR THE DEVELOPMENT OF EGGS OF G. OPERCULELLA

Box	No. Eggs	Date when Eggs laid	Date when Eggs hatch	Days	Temp. °C.	R.H.%
1	10	Jan.8,1963	Jan.18,1963	11	19-21	75-85
2	20	11, "	19, "	9	18-21	72-85
3	38	12, "	21, "	10	18-21	72-85
4	64	14, "	23, "	10	18-21	72-85
5	30	12, "	21, "	10	18-21	72-85
Total	162	Average		9.9		
6	7	July 20, "	July 23, "	4	31-32	77-85
7	16	23, "	27, "	5	31-32	74-85
Total	23	Average		4.7		

At first the color of the egg is pearly white. As incubation proceeds, the color darkens until it becomes dark metallic blue the last day or two before hatching. This color is due to the black head and prothoracic shield of the larva which by then can be seen through the transparent egg shell.

Hatching occurs as a result of the biting of the larva at the animal pole of the egg. In doing so, the larva makes a hole through which it emerges out of the shell. The newly-hatched larvae are sluggish or even motionless for a few hours unless disturbed. Each larva builds a web of white silk into which it retreats for a few hours, without any apparent activity.

When the eggs were kept continuously for 84 days (March 9 through May 31, 1963) at 10°C and 75 per cent and 90 per cent R.H. and then brought back to room temperature (27 to 28°C) and the same relative humidities, they showed signs of development (the bluish coloration of eggs) for six to seven days. The development, however, stopped just before hatching occurred.

Feeding and tunnelling started within 24 hours after hatching (including the few-hours period within the web). The feeding tunnels were made just beneath the tuber surface, but larvae of succeeding generations fed deeper and deeper inside until the whole tuber was spoiled (Fig. 6 and 7). The tunnels were sealed from outside with fecal matter (Fig. 8). The whole larval development required an average period of 29.4 days at 16 to 22°C. and 50 to 80 per cent R.H., while it took only 15 days at 31 to 32°C. and 80 to 85 per cent R.H. (Table III).

When the mature larvae were ready to pupate they became sluggish, retreated into the tubers or to corners of boxes, built cocoons of white silk and debris, and underwent pupation.

The pupal period lasted for an average period of 13.8 days at 18 to 22°C. and 50 to 85 per cent R.H., and for about 3.7 days only at 30 to 33°C. and 70 to 82 per cent R.H. (Table IV).

The adults emerge in a sex ratio of about one to one (Table VI). The rate of adult emergence reached its maximum on the 4th and 6th days after it started (Table V). Mating started within 24 to 48 hours after

TABLE III

PERIOD OF LARVAL DEVELOPMENT OF G. OPERCULELLA IN WINTER & SUMMER

Box	Larval and Pupal Development		Days	Temp.°C.	R.H.%
	From	To			
1	Jan.18,1963	Feb.27,1963	40	16-21	72-80
2	19, "	March 3, "	45	16-21	70-80
3	21, "	6, "	45	16-22	50-80
4	23, "	4, "	41	16-21	70-80
5	21, "	6, "	45	16-22	50-80
		Average	43.2		
	Pupal Development (from Table IV)		13.8		
	Larval Development Average		29.4		
	Egg-Adult (Table VIII)		23.4		
	Incubation Period	4.7			
	Pupal Period	3.7			
		8.4	8.4		
			15.0		
	Larval Development Average			31-32	80-85

TABLE IV

PERIOD OF PUPAL DEVELOPMENT OF G. OPERCULELLA IN WINTER AND SUMMER

Box	Date of Pupation	Date of Emergence	Days	Temp. °C.	R.H.%
1	Dec. 26,1962	Jan.19,1963	16	20-22	73-83
2	27, "	10, "	15	20-22	73-83
3	Jan. 1,1963	17, "	17	19-21	75-85
4	6, "	20, "	15	19-21	75-85
5	Feb.22, "	March 4, "	11	18-21	70-77
6	22, "	6, "	13	18-22	50-77
7	22, "	4, "	11	18-21	70-77
8	22, "	6, "	13	18-22	50-77
9	22, "	6, "	13	18-22	50-77
10	22, "	6, "	13	18-22	50-77
11	27, "	13, "	15	18-22	50-77
		Average	13.8		
12	July 16,1963	July 18,1963	3	30-32	80-82
13	Aug. 8, "	Aug. 10, "	3	31-33	80-82
14	8, "	12, "	5	31-33	70-82
		Average	3.7		

emergence from cocoons at 21 to 22°C. and 77 to 80 per cent R.H. The copulation lasted for more than two hours. Egg-laying started within 24 hours after mating in winter and spring, while in summer, at 31 to 33°C. it was almost stopped, or, at best, delayed until the 3rd to 7th days after emergence of the adults with very few eggs laid. In the present experiment, for example, two females laid a total of 9 eggs and died, and a set of 19 moths laid only 7 eggs, seven days after their emergence.

Eggs were laid around buds and cracks of tubers and beneath their peeled skins. They were laid singly, in chains of 3 to 12 eggs, or in batches of 2 to 20 eggs. The average number of eggs laid by a single female on tubers (eggs laid on bottom and sides of cage were not counted because of technical difficulties) was only about 9 eggs (Table VI). When a fertilized female was isolated in a vial it laid a total of 38 eggs before it died.

The adults lived for an average period of 14.5 days in winter at an average temperature of 20°C. and a relative humidity of 80 per cent and for an average of 6.2 days in summer at 32 to 33°C. and 74 to 83 per cent R.H. The rate of their death, like

TABLE V.

RATE OF EMERGENCE OF IMAGOES OF G. OPERCULELLA IN TWO SEPARATE CAGES

CAGE NO. 1		CAGE NO. 2	
Date	No. of Emerging Moths	Date	No. of Emerging Moths
Jan. 3, 1963	3	Jan.11,1963	3
6, "	1	12, "	4
7, "	8	14, "	8
8, "	6	16, "	13
9, "	3	18, "	9
10, "	5	21, "	9
		23, "	5
		25, "	6

TABLE VI

SEX RATIO OF ADULTS AND NUMBER OF EGGS LAID ON TUBERS BY 39 FEMALES OF G. OPERCULELLA

No. of Adults	No. of Females	No. of Eggs	Average No. of Eggs/Female
51	26	166	6.4
27	13	141	10.8
78	39	307	8.6

that of their emergence, reached its maximum on the 5th to 6th day after it started (Table VII). In general, the females lived two to three days longer than the males. They did not show any feeding activity, but when a freshly-cut tuber and a piece of cotton soaked with 10 per cent sugar solution were introduced into the cage they began feeding actively, especially the females, mostly from the cut tuber. In general, the moths were more active at night, although mating and egg-laying were observed during the day.

The development of a complete generation, from egg to egg, required an average period of 55.1 days at 16 to 22°C. and 70 to 85 per cent R.H., and only about 28.4 days at 31 to 33°C. and 77 to 85 per cent R.H. (Table VIII).

The rate of mortality during the different stages of development under laboratory conditions was very high, it was almost 76 per cent (Table IX). The monthly mean temperatures and relative humidities of the laboratory during the period of the present work are shown in Table X.

TABLE VII

RATE OF DEATH OF IMAGOES OF G. OPERCULELLA IN TWO SEPARATE CAGES

Cage No. 1		Cage No. 2	
Date	No. of Dead Moths	Date	No. of Dead Moths
Jan.14, 1963	3	Jan.21, 1963	2
18, "	3	23, "	8
19, "	5	25, "	11
23, "	4	26, "	2
25, "	2	27, "	1
27, "	1	-	

TABLE VIII

PERIODS REQUIRED FOR THE DIFFERENT DEVELOPMENTAL STAGES OF G. OPERCULELLA IN WINTER AND SUMMER

Winter & Spring 16-22°C.		Summer 31-33°C.
Stage	Days	Days
Egg	9.9	4.7
Larva	29.4	15.0
Pupa	13.8	3.7
Egg-Adult	53.1	23.4
Adult until eggs are laid	2.0	5.0
Egg - egg	55.1	28.4

TABLE IX

RATE OF MORTALITY OF G. OPERCULELLA THROUGH ITS DEVELOPMENT IN THREE SEPARATE CAGES

Cage	No. of Eggs	No. of Emerging Adults	% Emergence	% Mortality
1	64	13	20.3	79.7
2	64	19	29.7	70.3
3	102	23	22.6	77.4
Total	230	55		
Average			23.9	76.1

TABLE X

MONTHLY MEAN TEMPERATURES AND RELATIVE HUMIDITIES OF THE LABORATORY (NOVEMBER THROUGH AUGUST)

Month	Temp.°C.	R.H.%
Nov., 1962	24.9	69.2
Dec., 1962	20.1	76.8
Jan., 1963	19.8	78.4
Feb., 〃	19.0	73.0
March, 〃	20.8	64.9
April, 〃	23.0	74.0
May, 〃	28.0	76.0
June, 〃	27.5	80.5
July, 〃	31.4	79.4
Aug., 〃	31.9	80.4

B. DISCUSSION

The finding that moths start mating within 24 to 48 hours after they emerge from their cocoons, and lay eggs about 48 hours after their emergence agrees with those of Lloyd (1943-44).

The total number of eggs laid seems to be determined by temperature. Thus, in winter and spring at 18 to 21°C., the number of eggs per female was around 9 eggs and reached as high as 38, while in summer at 31 to 33°C. the number was as low as 1 to 4 eggs. Such a decrease in the number of eggs is probably due to higher temperature; a suggestion that is confirmed by Attia and Mattar (1939) who report the critical temperature for G. operculella (Zell.) to be about 36°C., above which no eggs are laid and the moths die quickly. Also, they report the optimum temperature to be 28°C. at which eggs are laid at the highest rate. This condition is also confirmed by Lloyd (1943-44) who reports the optimum temperature for egg-laying to be 29°C. The number of eggs laid per female reported

in literature varies (Bartoloni, 1951; Dutt, 1914; Whitehead, et.al., 1953). Such variations in the reported number of eggs laid seems to be due either to different ranges of temperature fluctuations in the geographical areas where those authors worked, or possibly due to the existence of different strains of G. operculella (Zell.) which differ in their prolificity (Such supposed strains are not yet reported), or to both of these factors. However, Attia and Mattar (1939) in Egypt report the number of eggs obtained in their breeding studies to lie between 3 and 134 eggs per female, and that it is highest at 28°C. The number of eggs reported in the present work is less than that reported by Attia and Mattar (1939) in Egypt and that reported by Bartoloni (1951) in Italy.

The decrease in the number of eggs laid in summer is compensated for by the rapid development of the different stages (see below).

The shape of egg masses, as well as the number of eggs per mass, are determined by the nature and size of substratum. Thus, although Metcalf et.al. (1962) report that eggs are laid one in a place, in the present work the eggs were found laid singly in

very small pits and buds, in batches of 2 to 20 eggs in larger pits and buds, and in chains of 3 to 12 eggs in narrow long cracks. Such a finding agrees with that of Lloyd (1943-44).

The period required for the development of the embryo and the subsequent stages varies inversely with temperature. Thus, the incubation period of the egg is found to be about 9.9 days in winter at 18 to 21°C., while in summer at 31 to 32°C. the period is only about 4.7 days. These results agree with those of Bartoloni (1951) in summer, and differ from his findings in winter of Italy which is cooler than that of Beirut. At low temperatures, for example at 10°C. no hatching occurs. This finding is in agreement with that of Picard (1914).

The larval development requires about 29.4 days in winter at 16 to 22°C., while it requires about 15 days in summer at 31 to 32°C. These findings agree with those of Bartoloni (1951) in summer, and Metcalf et.al. (1962).

Pupation is observed to occur mostly outside the tubers; an observation which confirms that of Metcalf et.al. (1962). The pupation period lasts for about 13.8 days in winter at 18 to 22°C., and 3.7 days

in summer at 30 to 33°C. This observation is in agreement with those of Bartoloni (1951) and Metcalf et.al. (1962).

The time required from the start of egg-laying until the end of pupation varies between an average of 53.1 days in winter and 23.4 days in summer. This finding fairly agrees with that of Lloyd (1943-44) who reports the period to be 54.3 days in winter at 15.5 to 21°C. and 19 to 20 days in summer at 29°C. under laboratory conditions.

The sex ratio of the moths is about one to one. Being nocturnal in its activity means that the moth prefers the lower ranges of temperature and the higher ranges of relative humidity. Such a suggestion is based on results reported in the literature and in the present work, and on the fact that in potato store houses, where the moths thrive, the temperature is lower and the relative humidity is higher than outside. On the other hand, the reports of Metcalf et.al. (1962) and Langford and Cory (1932) that hot dry years favor the development of the moth, do not seem to contradict the above statement, since hot dry weather means rapid development of the moth and more generations per year.

The finding that the development of a complete generation (from egg to egg) requires 28.4 days in summer agrees with that reported by Bartoloni (1951). The results of this study show that in winter it requires 55.1 days for the development of such a complete generation; this agrees with that of Dutt (1914), but is much less than the time reported by Bartoloni (1951) from Italy.

As the temperature rises the number of generations per year increases. Under the prevailing weather conditions in Lebanon, there is a possibility of having more than 7 or 8 generations a year in the laboratory.

Fluctuations in relative humidity within the higher range of 70 per cent to 90 per cent, which is the prevailing range in Beirut throughout the year, does not seem to adversely affect the development of G. operculella (Zell.) to any extent; it seems that the moth prefers such a range. On the other hand, development is greatly affected by a change of even three or four degrees centigrade; such change during the growth of the insect may cause a difference of several days, as well as a change in the number of eggs laid per female.

Thus, temperature, besides other factors, seems to be the prime factor that controls the speed of development of G. operculella (Zell.) This information is based on findings in the present work, and confirms the works of Picard (1912), Attia and Mattar (1939), and Lloyd (1943-44).

CONCLUSIONS

1. The potato tuber moth Gnorimoschema operculella (Zell.), a cosmopolitan pest, is a major pest of field and stored potatoes.
2. In its development, the potato tuber moth shows inverse relationship to temperature:
   a. At the lower range of temperature, i.e. 16 to 22°C., one generation requires an average of 55.1 days to be completed.
   b. At the higher range, i.e. 31 to 33°C., the time required for the development of one generation is reduced to about 28.4 days.
   c. At the lower temperature extremes, for example, 10°C., the eggs do not hatch.
   d. At the higher temperatures, 31 to 33°C., the number of eggs laid decreases, while at 36°C. egg-laying stops and the moths die.
   e. The optimum temperature range for egg-laying and for development is around 28 to 29°C. at 70 to 90 per cent R.H.

3. The moths continue to reproduce in store houses, and in the laboratory as well, as long as there is enough food to maintain the larvae, an air temperature ranging between 16 and 29°C., and a relative humidity of 70 per cent and above.
4. Under the prevailing weather conditions in Lebanon there is a possibility of having more than 7 or 8 generations a year.
5. Damage to the potato tubers is done by larvae which feed by digging tunnels, first superficial, then deeper, through the tubers.

SUMMAR

The life-history of the potato tuber moth Gnorimoschema operculella (Zell.) was studied in the laboratory, starting in November 1962 until August 1963. The larvae were reared on potato tubers which are their main food. As soon as eggs were laid on cracks and buds of tubers, the tubers were removed to plastic boxes and were examined daily until the eggs hatched. Development of the larvae and pupae, and the activity of the adults were observed. The time required for the completion of each stage and

temperature and relative humidity then prevailing were recorded. The development of one generation in winter and spring was found to require almost two months, while in summer it was found to require about one month only.

The larval stage of this insect is directly responsible for the damage caused to potato tubers.

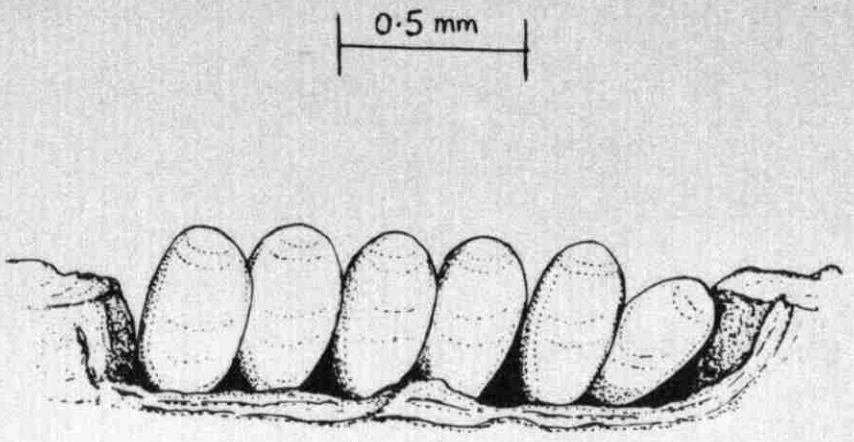
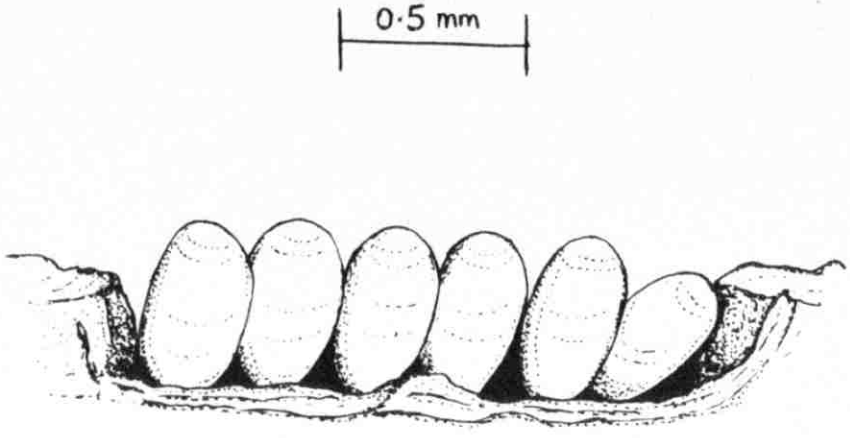


Fig. 1. Eggs of G. operculella (Zell.) in a crack on a tuber.



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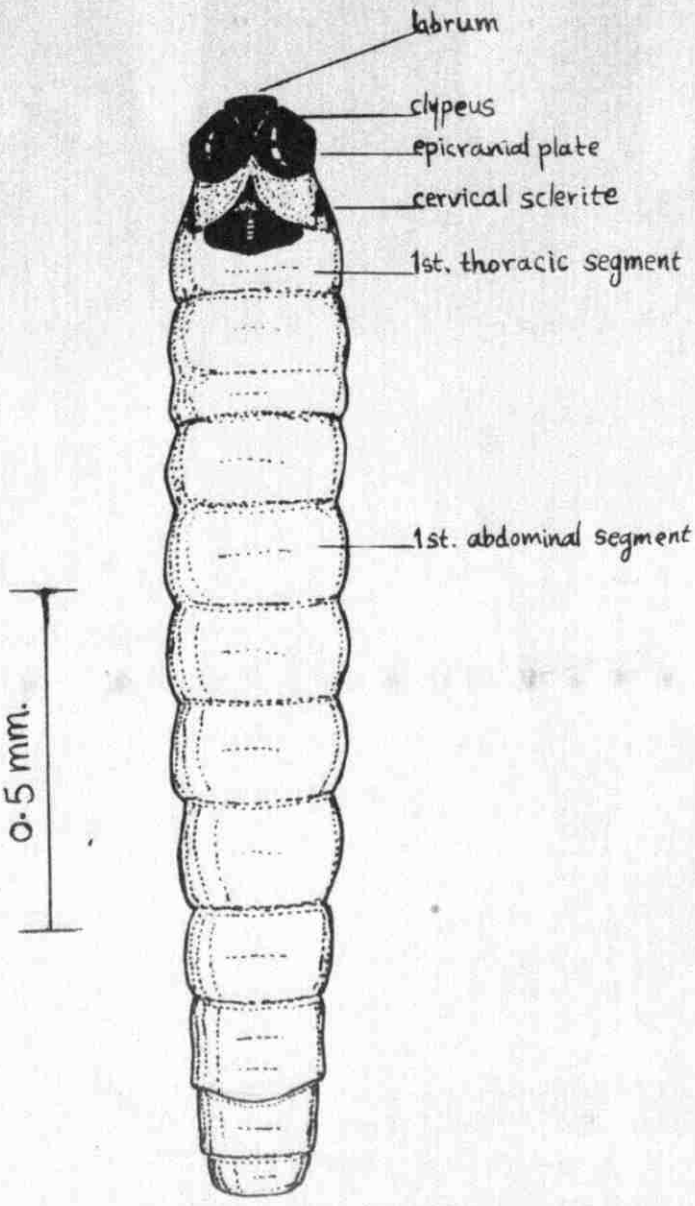

Fig. 2. First-instar larva of G. operculella (Zell.)

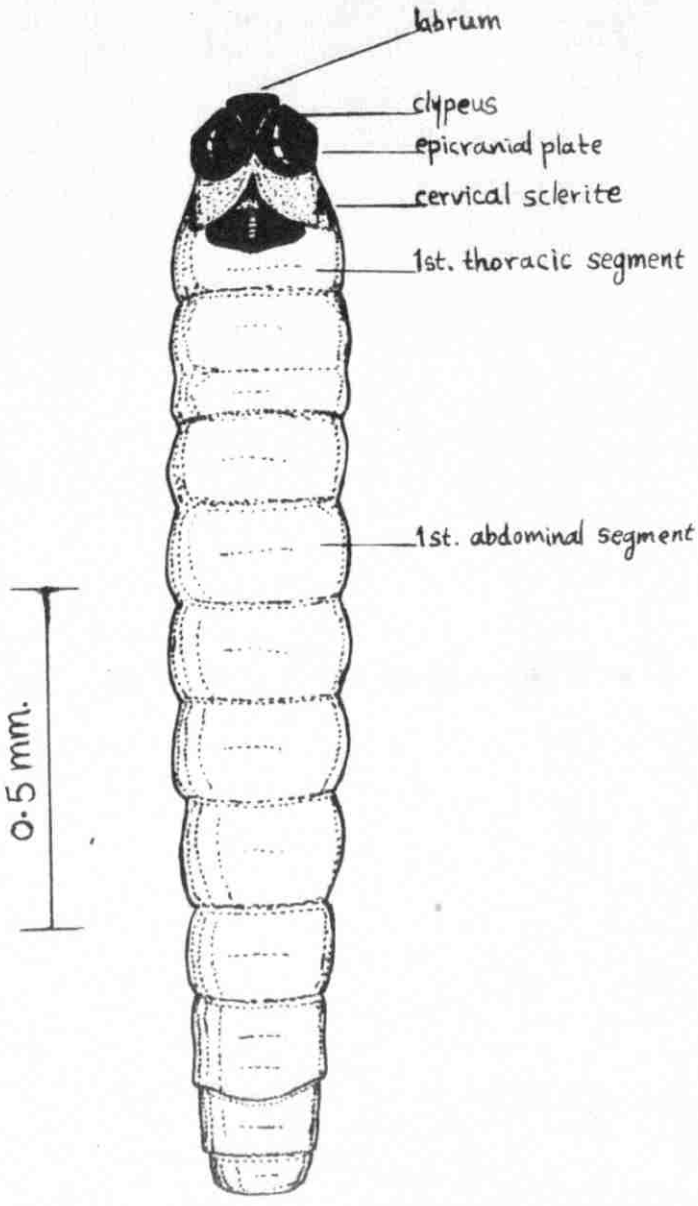

Fig. 2. First-instar larva of G. operculella (Zell.)

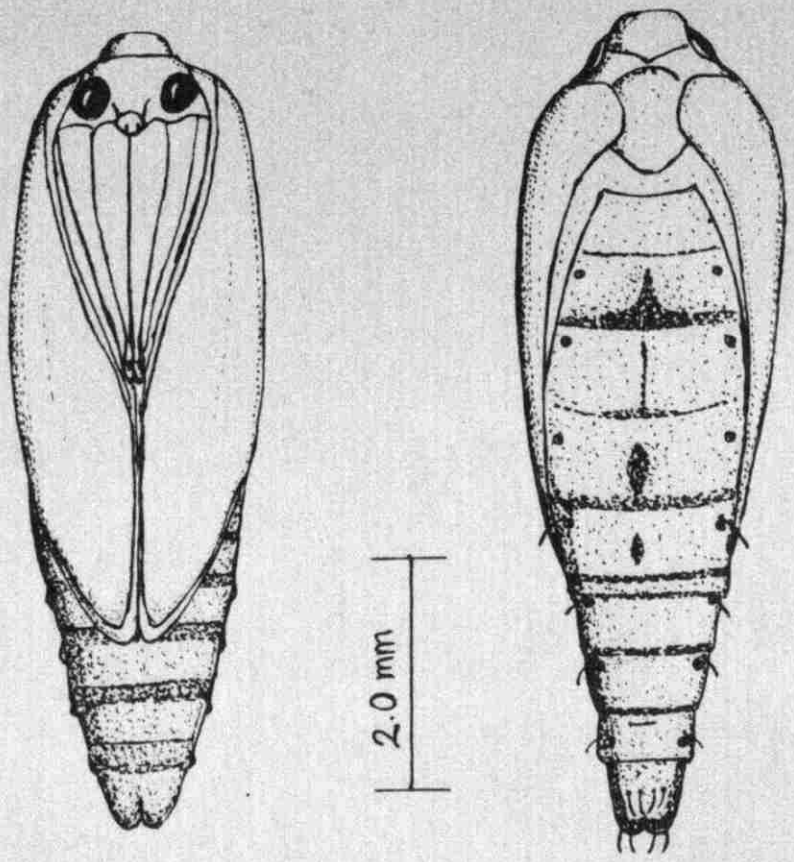

Fig. 3. Pupa of G. operculella (Zell.), ventral (left) and dorsal (right) views.

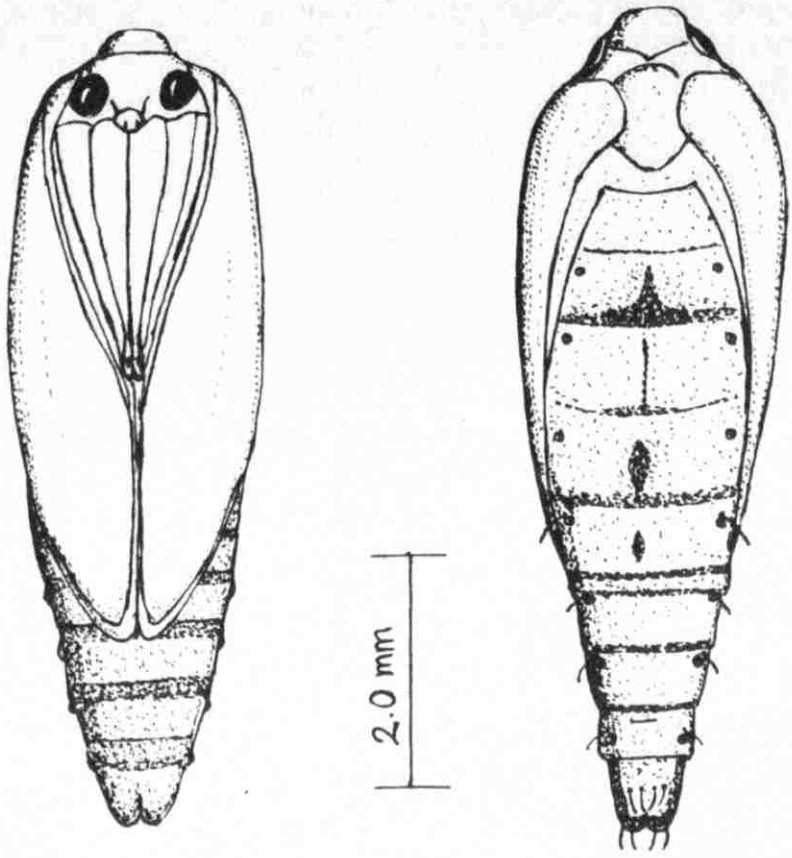

Fig. 3. Pupa of G. operculella (Zell.), ventral (left) and dorsal (right) views.

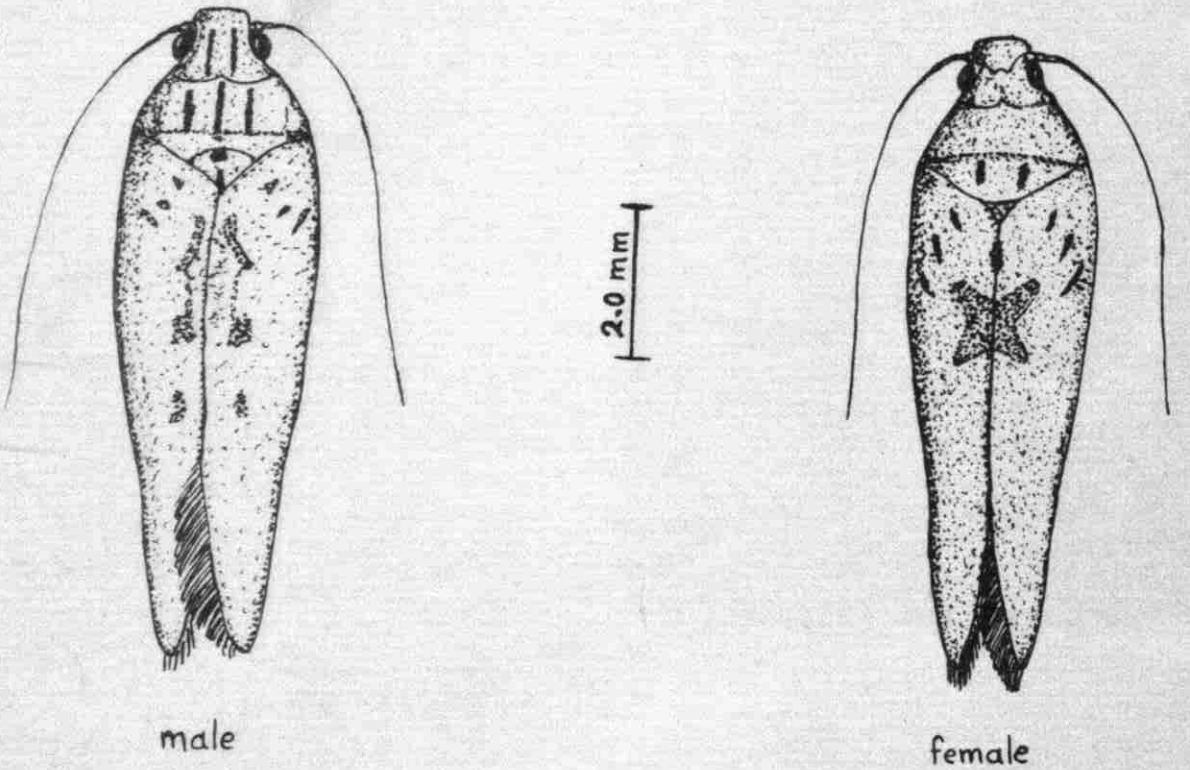

Fig. 4. Male and Female G. operculella (Zell.), dorsal view.

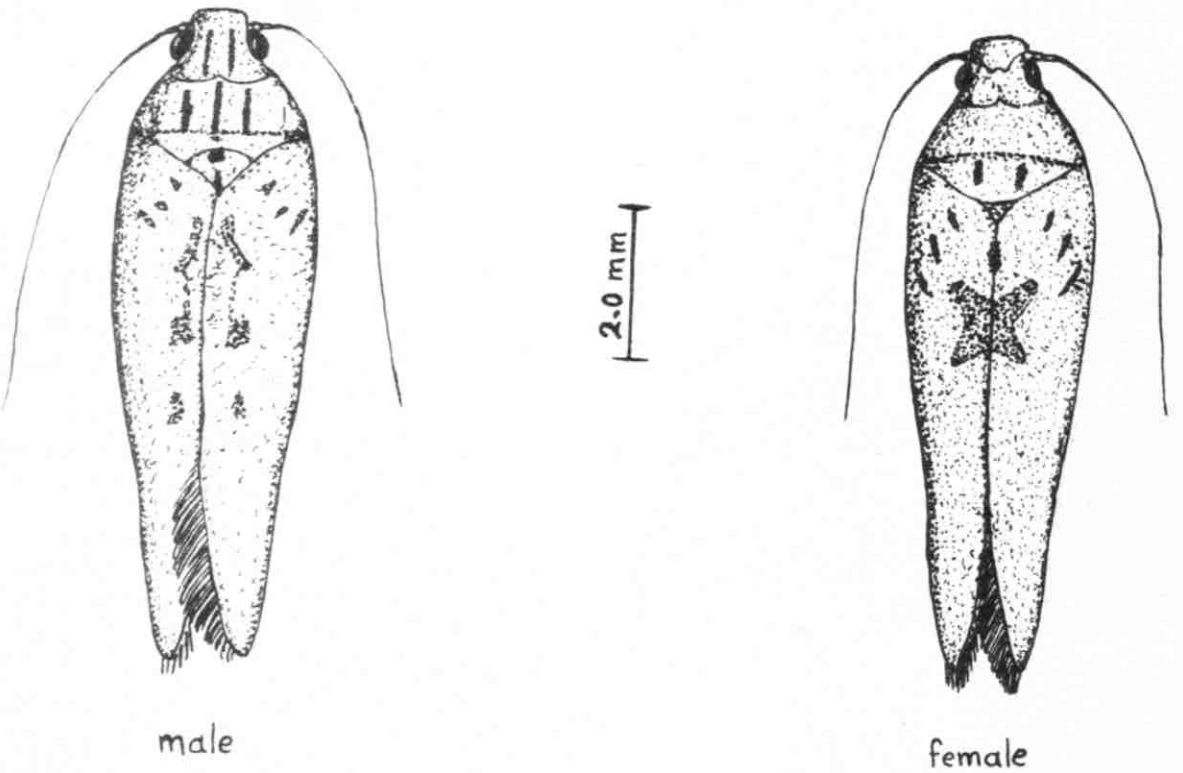

Fig. 4. Male and Female G. operculella (Zell.), dorsal view.

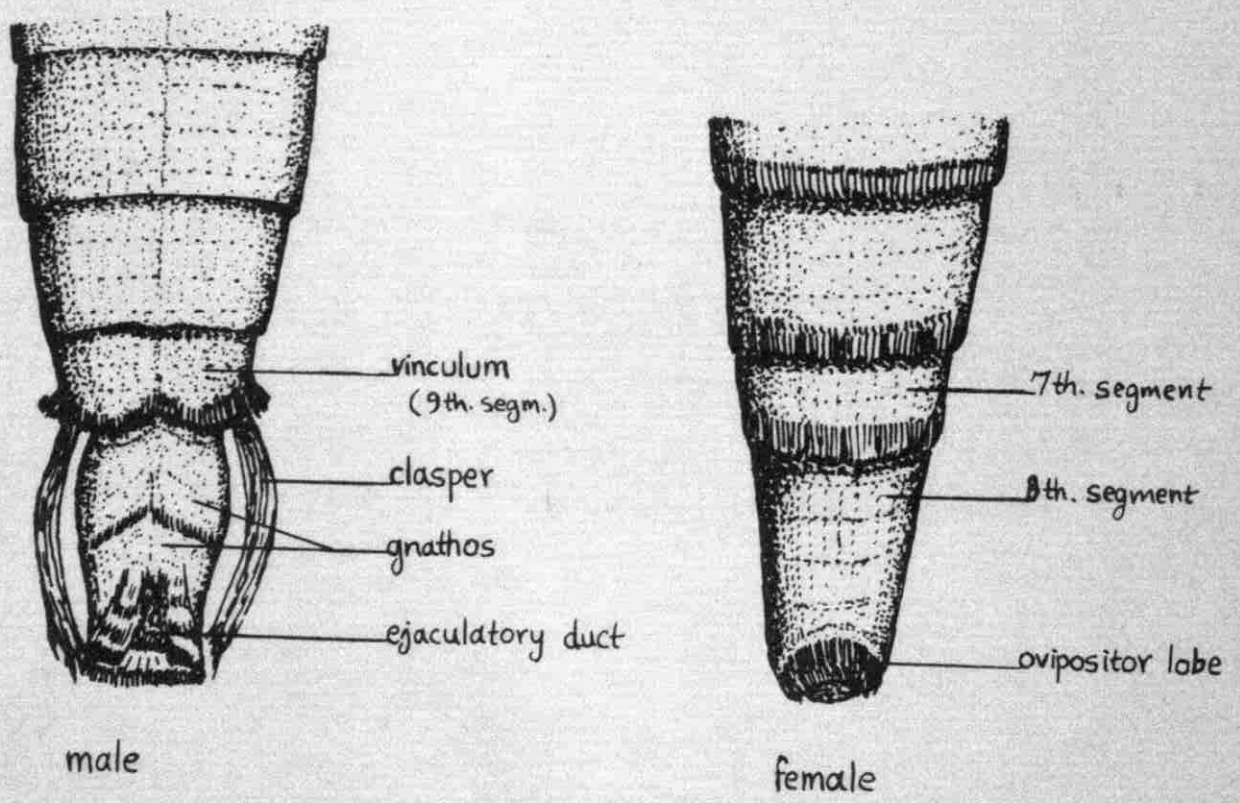

Fig. 5. Abdomens of male (left) and female (right) G. operculella (Zell.), ventral view.

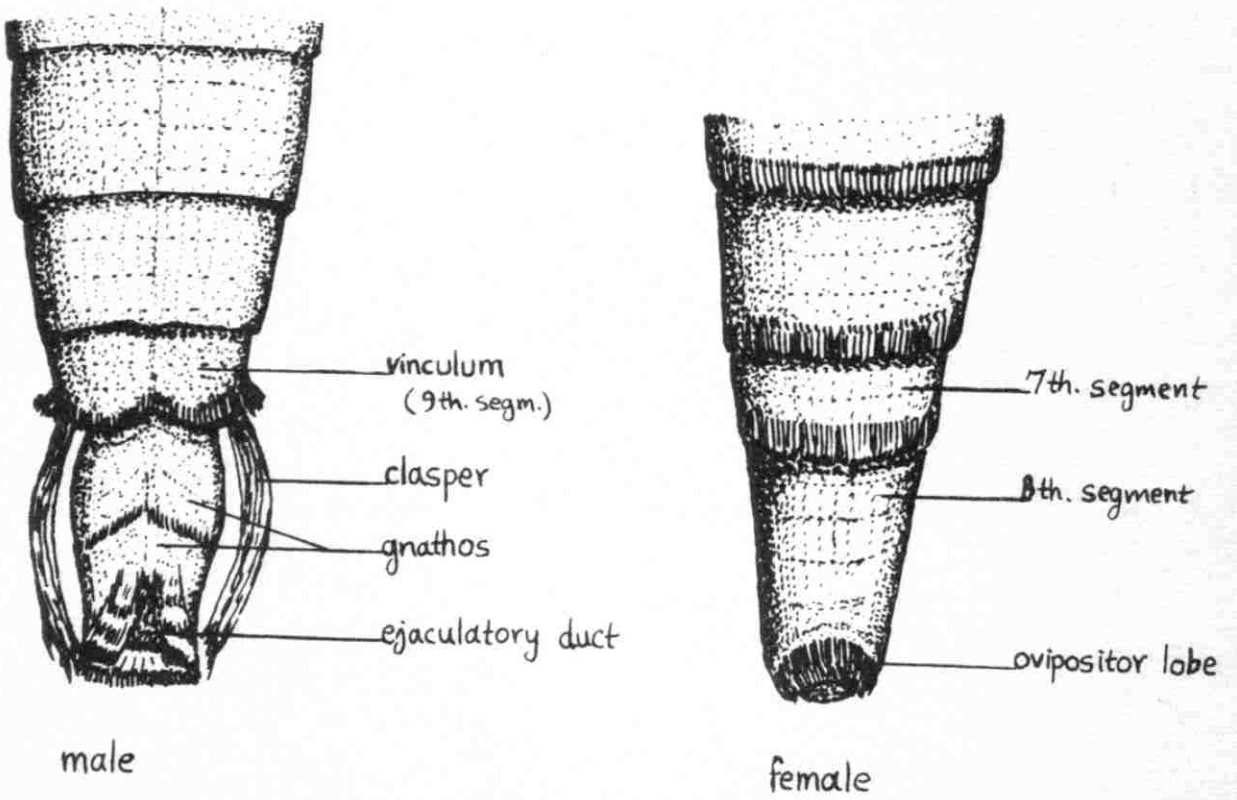

Fig. 5. Abdomens of male (left) and female (right) G. operculella (Zell.), ventral view.

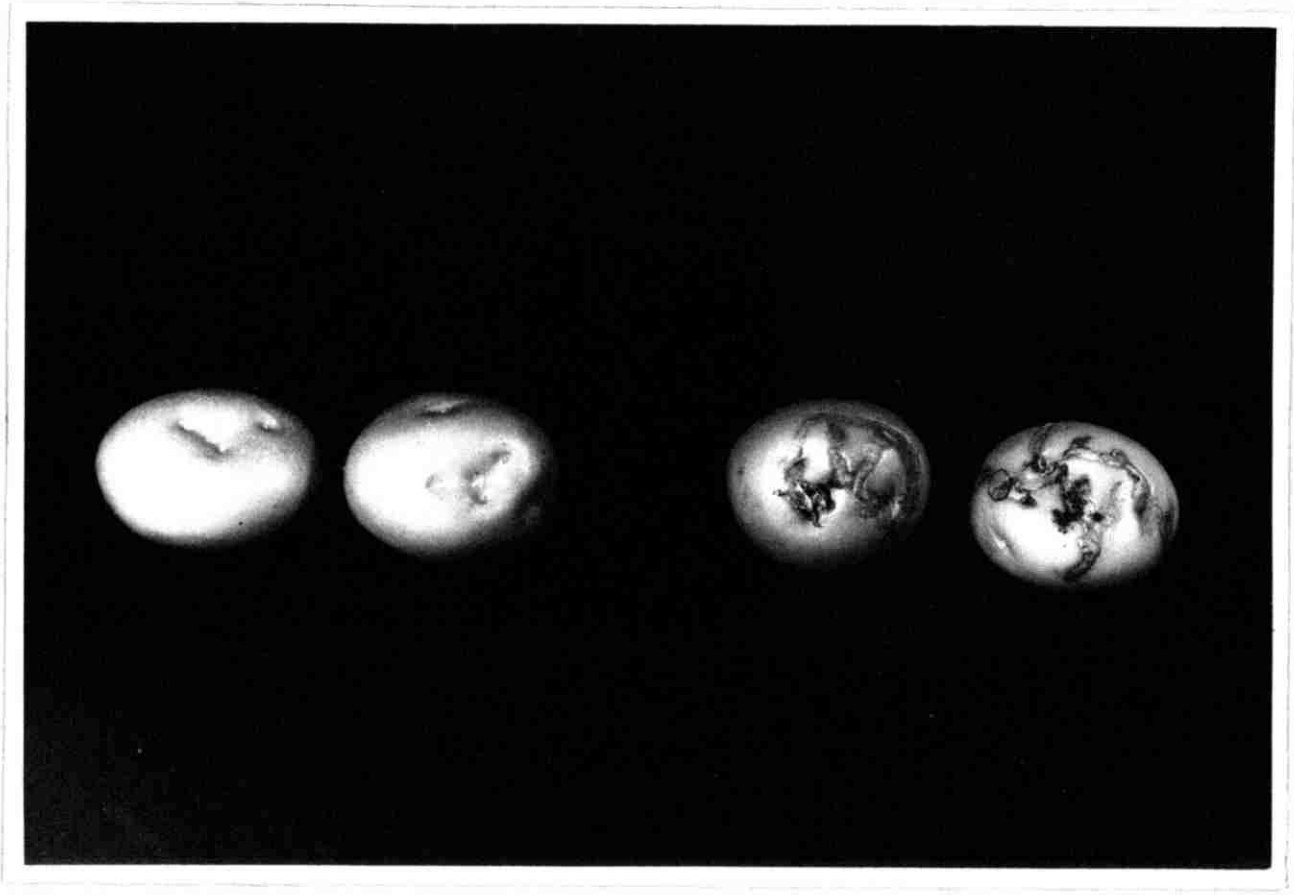

Fig. 6. Sound (left) and infested (right) potato tubers. The irregular tunnels are dug by larvae just beneath the surface at early infestation. The circle on the right tuber indicates the site of oviposition from which tunnelling starts.

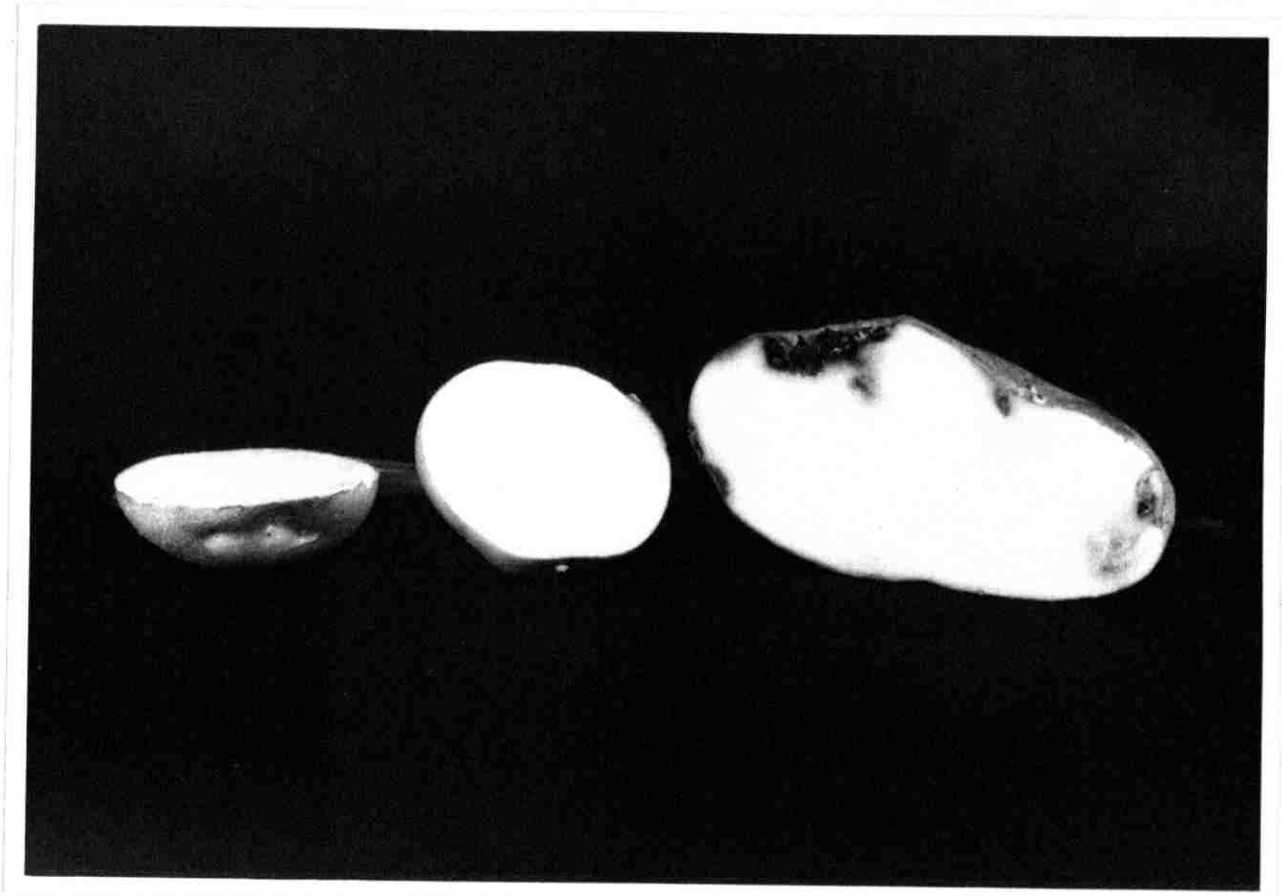

Fig. 7. Sound (left) and infested (right) potato tubers cut open for comparison. Superficial tunnels indicate early infestation. Larvae of succeeding generations dig deeper until the whole tuber is spoiled.

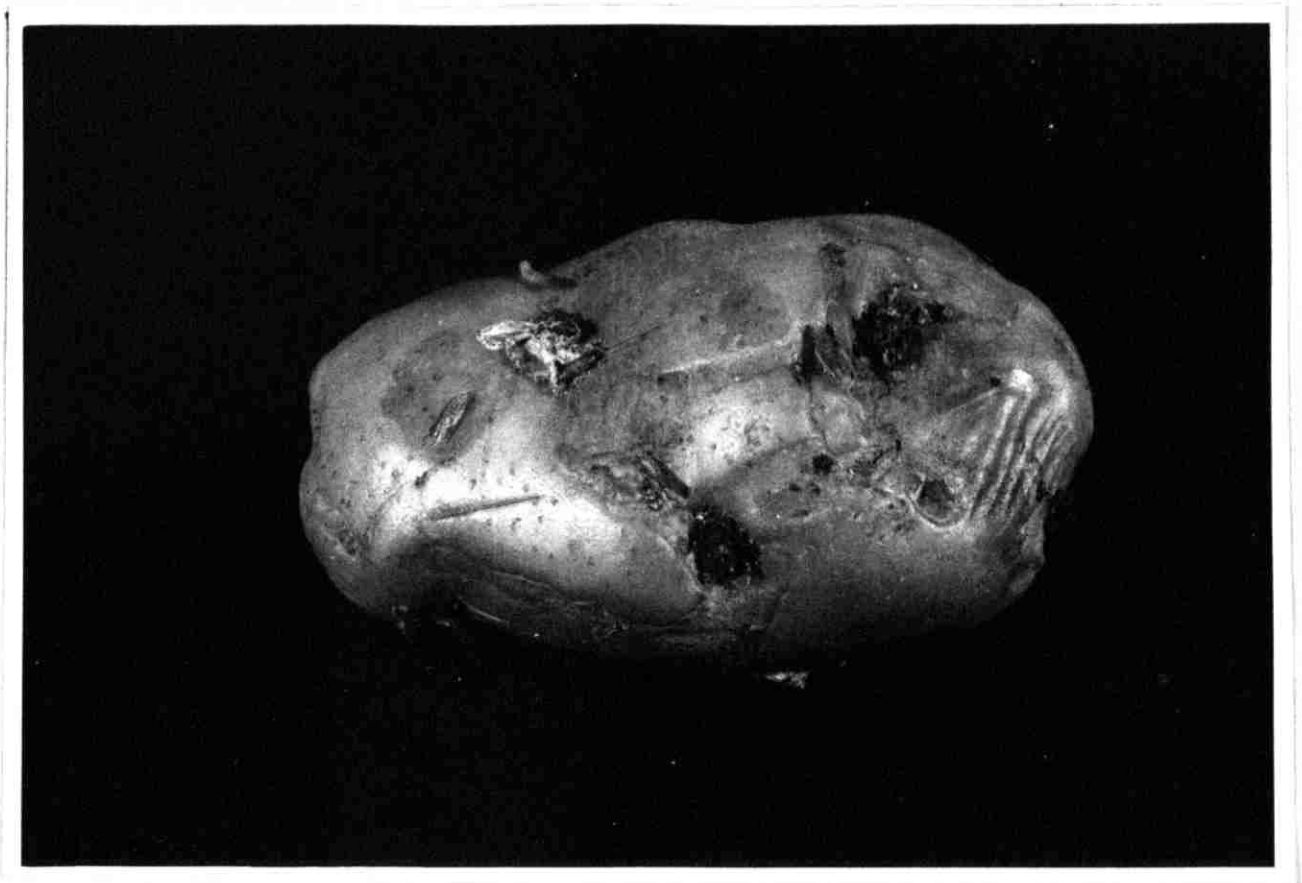

Fig. 8. A potato tuber infested with G. operculella (Zell.). A mature larva is shown at the upper left, two pupae just below the larva, and two adults: one at lower left and the other at lower right to pupae. Note the black fecal matter and frass that seal the tunnels.

PART II

CONTROL IN STORAGE

REVIEW OF LITERATURE

Biological Control

Mueseback (1921) in the United States and Usman (1957) in India reared the Ichnenmonid wasps Apanteles scutellaris and Campoplex sp. respectively from larvae of G. operculella (Zell.) Sagot-Lesage (1923) reported the successful establishment of the Braconid wasp Habrobracon johanseni as a parasite of G. operculella (Zell.) in France, resulting in a marked decrease in the number of infested potatoes.

Among the predators reported from New Zealand were the Syrphid flies Syrphus novae-zealandiae and Melanostoma fasciatum which prey on larvae of G. operculella (Miller, 1918). Russel (1936) reported the ant Pheidole megacephala from Bermuda, while Trouvelot (1924) reported P. pallidula from France. Formica fusca subsericea and Lasius niger americanus were reported by Underhill (1926) from the United States. Other predators include the bugs Podisus

maculiventris and Lyctocoris campestris reported from the United States by Underhill (1926) and the mite Pediculoides ventricosus reported from France by Trouvelot (1924).

However, all these species were reported as field parasites and predators only. In storage the moth larvae are not accessible to the parasites (Usman, 1957). Accordingly, they are ineffective in controlling the moth in stored potatoes.

Cultural Control

This includes many recommendations and measures to protect sound tubers from infestation. The most important and most widely-used measure is the covering of sound tubers with one-inch layer of sand. This was successfully demonstrated in India (Coventry, 1913) where it is still practiced giving complete or nearly-complete protection to sound tubers (Rahman, 1944; Lal, 1945; and Chaudhuri, 1958). Potatoes can be stored successfully beneath sand for as long as eight to nine months (Bartoloni, 1951). However, if some infested tubers are stored with sound ones beneath sand, the infestation spreads

to sound tubers beneath and outside the sand cover (Chaudhuri, 1958).

Other cultural measures include:

1. Cutting and burning of infested vines a few days before digging the tubers (Metcalf, et.al., 1962).
2. Grazing of infested plants by sheep and pigs (Chittenden, 1912).
3. Use of poultry in the store house (Mercet, 1925).
4. Storage of tubers at temperature below 10°C. (Bartoloni, 1951).
5. Hot-water (180°F) treatment to kill the pupae (Armitage, 1946).
6. Crop rotation (Chittenden, 1912).

Chemical Control

The potato tuber moth G. operculella (Zell.) is chemically-controlled either by fumigants or by contact insecticides. Fumigation with carbon bisulfide (CS_2) was recommended almost 50 years ago (Stoward, 1913) supplied at a rate of 1 to 2 lb./1000 cu. fit. for 15 to 16 hours to kill the larvae, and for 48 hours to kill the eggs and pupae. Scholl et.al. (1914) recommended a higher dose; i.e., 3 lb./1000 cu.

ft. for a shorter period of 3 hours. Fumigation with carbon bisulfide is still practiced at a modified rate of 1 lb./1000 cu.ft. for 12 hours at 88 to 97°F., which kills all the stages. Higher dosages or a longer time of exposure encourages rotting of the tubers (Chaudhuri, 1958). Delassus (1926) recommended p-dichlorobenzene (PDB) at a rate of 1 oz./35 cu.ft. which killed all the larvae and freed the tubers from infestation within 48 hours, while the germination of tubers was not affected. Another important fumigant is methyl bromide (CH_3Br) which was first tried to control G. operculella (Zell.) by Mackie and Carter (1937) at a rate of 2.5 lb./1000 cu.ft. for 90 minutes. Later, Mackie et.al. (1939) modified this dosage to 2 lb./1000 cu.ft. for 120 minutes. Walker and Anderson (1944) reported the fumigation of infested potatoes with methyl bromide at a rate of 2.4 lb./1000 cu.ft. for 15 minutes only, which resulted in 100 per cent killing of all the stages and in the protection of all fumigated potatoes throughout autumn to spring from further infestation. When these fumigated potatoes were planted, most of them grew normally. The same authors reported the complete protection of sound tubers after their storage in a store house which had been fumigated and kept closed for 36 hours.

Lubbati and Bunday (1958) reported similar results and added that methyl bromide residue was not more than 0.05 to 1.3 ppm. which could be eliminated by boiling the potatoes.

Among contact insecticides DDT, $Cl_3C\text{-}CH(C_6H_4Cl)_2$, is the most widely used. Direct shaking of tubers with 5 per cent DDT for 30 minutes was reported by Pingale et.al. (1954) to give complete protection to tubers, but the residue, even after 6 months, was not completely removed by washing or boiling. When these treated tubers were fed to rats for two months they caused harmful changes in their livers. Hofmaster and Anderson (1948) stored sound tubers in burlap and muslin bags impregnated with different concentrations of DDT in xylene. All concentrations, 1 to 5 per cent, gave 100 per cent protection to tubers, and the residue left after six and a half months was enough to kill the moths that were then introduced. Chaudhuri (1958) recommended the use of DDD (TDE), p,p′-dichlorodiphenyl dichloroethane (tetrachloro diphenyl ethane), which gave excellent protection to sound tubers, and was much safer to use on table potatoes than DDT. Toxicity of DDD to higher animals is almost one-tenth that

of DDT in acute LD_{50} and 1/25 in chronic LD_{50} (Brown, 1951).

Another excellent contact insecticide is Lindane (Gamma-BHC) which gives 100 per cent protection to tubers directly dusted or stored in treated bags and boxes (Lloyd, 1951). However, its toxicity to higher animals is about 2.5 times that of DDT (Brown, 1951).

Sevin (1-Naphthyl N-Methylcarbamate) has been used as a contact insecticide against many field pests only recently (Haynes et.al., 1957). Against G. operculella (Zell.), it has been tried only very recently when Bacon (1960) reported it to be very effective against that moth in the field. A survey through available literature shows that it has not been tried yet against G. operculella (Zell.) in storage. Haynes et.al. (1957) reported that its toxicity to mammals appeared to be low, and that its residual effect was intermediate between that of DDT and TEPP (Tetraethyl pyrophosphate).

MATERIALS AND METHODS

The experiment consisted of storing clean potato tubers in burlap bags which had been treated with three contact insecticides at two concentrations each, and exposing the bags to the fertilized potato tuber moths.

The insecticides used were:

1. DDT (p,p' -Dichlorodiphenyltrichloroethane) 25 per cent emulsifiable concentrate (Nordisk Alkali Biokemi Ltd. Copenhagens); at 1 per cent and 2 per cent concentrations.
2. Lindane (Gamma isomer of hexachlorocyclohexane) 20 per cent emulsifiable concentrate (Selchim, Bruxelles); at 0.1 per cent and 0.5 per cent concentrations.
3. Sevin (1-Naphthyl N-methylcarbamate) 85 per cent by weight (Union Carbide International Co., U.S.A.); at 0.6 per cent and 1.2 per cent concentrations.

Seven treatments were performed. In each of them four bags were used. Each treatment was repli-

cated three times, making a total of 12 bags. The bags of each treatment were immersed in a water dilution of one of the insecticides, and were kept for 24 hours in order to make sure that the burlap absorbed enough of the insecticide. After 24 hours the bags were left to dry in the shade before the tubers were introduced. The total number of bags impregnated was 72; the last 12 bags being left as controls. Thus, 84 bags, each measuring 20 x 25 cm. approximately, were prepared, as shown in Table XI.

Four to six sound tubers were put in each bag, the bag mouth was tied tightly, and every four bags treated with a given concentration were put together in a wooden cage. Six adult moths, 3 males and 3 females were introduced in every cage in order that the females may lay eggs on the bags. Freshly-cut potatoes were also introduced into the cages to serve as food for the moths. The moths were introduced between the 12th and the 23rd of August, 1963.

Each cage measured 57 x 57 x 85 cm., with the top and three sides covered with wire netting of fine mesh, the bottom made of wood, and the fourth side served as a glass door into which a smaller door

was fitted. The cages with bags were put in the basement of the Biology Department, where the temperature ranged between 28 and 29°C. and the relative humidity between 88 and 95 per cent.

TABLE XI

CONCENTRATIONS AND REPLICATES OF THE THREE INSECTICIDES TESTED

Insecticide	Concentration %	Replications	Bags per Rep.	Total Bags	Total Cages
DDT	1	3	4	12	3
	2	3	4	12	3
Lindane	0.1	3	4	12	3
	0.5	3	4	12	3
Sevin	0.6	3	4	12	3
	1.2	3	4	12	3
Control	-	3	4	12	3
Total				84	21

RESULTS AND DISCUSSION

The sets of bags for each treatment were examined twenty days after the introduction of moths. This period was long enough for egg-laying and for the larvae to develop and reach the pupal stage. The criterion used to measure the effectiveness of the insecticides tested was the severity of infestation. The severity of infestation was determined by the number of tunnels per tuber and the length of such tunnels. The results are tabulated in Table XII.

The figures in Table XII show that the three insecticides are equally effective in killing 100 per cent of the adults of G. operculella (Zell.) within 48 hours and in 100 per cent protection of sound tubers from infestation. Some of the clean tubers that had been cut and put exposed in all cages to serve as a source of food for the adults, were found infested with larvae despite the presence of chemically-treated bags in the same cages. Whether the moths laid eggs on the treated bags before they died and the emerging caterpillars died before reaching the tubers, or whether the moths were killed before they

TABLE XII

EFFECTIVENESS OF DDT, LINDANE, AND SEVIN IN PROTECTING BAGGED POTATOES FROM INFESTATION WITH G. OPERCULELLA (ZELL.)

Insecticide	Concentration %	% Adults Killed in 48 hours (3 Replicates)	Tubers Infested in 20 Days (3 Repl.)	% Tubers Infested in 20 Days (3 Repl.)	Total No. of Tunnels (3 Repl.)	Total Length of Tunnels in mm. (3 Repl.)	Tunnels per Tuber	Average Length of Tunnels per Tuber in mm.
DDT	1	100	0	0	0	0	0	0
	2	100	0	0	0	0	0	0
Lindane	0.1	100	0	0	0	0	0	0
	0.5	100	0	0	0	0	0	0
Sevin	0.6	100	0	0	0	0	0	0
	1.2	100	0	0	0	0	0	0
Control	-	16.6	29	51.7	81	1649	2.8	56.8

were able to lay on the bags could not be ascertained. The first assumption, however, seems to be the more logical one since the moths were able to lay on the "nutritional" tubers.

The effectiveness of DDT is in complete agreement with the findings of Hofmaster and Anderson (1948). As for Lindane, the results of the present work also agree with those of Lloyd (1951). The concentrations of Lindane used in the present experiment (0.1 per cent and 0.5 per cent) proved to be as effective as the higher ones (1 per cent and 3 per cent) used by Lloyd (1951). Sevin proved to be as effective against G. operculella (Zell.) as DDT and Lindane. Because of its recent synthesis the available literature shows that it has not yet been used against G. operculella (Zell.) in storage. A recent paper by Bacon (1960) reports that it was applied against G. operculella (Zell.) as a spray on potato vines in the field at a rate of 1.5 lb. per acre per application. The applications resulted in only 1.3 per cent infestation of tubers. Thus, zero per cent infestation of tubers in storage in the present work can be considered to agree with the finding of Bacon (1960).

When no insecticide was used (control), more

than half of the bagged tubers became infested within twenty days of the introduction of moths. This means that if such tubers are stored for a longer time, all of them would be severely infested and spoiled by G. operculella (Zell.)

The results discussed above show that the three insecticides, DDT, Lindane and Sevin, proved to be equally effective against G. operculella (Zell.) in storage. The one to be recommended for use against this moth must show certain advantages over the others, such as low cost, longer residual action and lower mammalian toxicity. As for mammalian toxicity, the oral LD_{50} for Lindane is 125 mg per Kg. of body weight, for DDT it is 250 mg per Kg. (Brown, 1951), and for Sevin it is 540 mg per Kg. (Metcalf et.al., 1962), which means that Sevin is the least toxic while Lindane is the most toxic of the three. Moreover, the carbamate group to which Sevin and related compounds belong is more rapidly detoxified and eliminated from animal tissues than DDT and Lindane, and thus is not stored in fats or excreted in milk (Metcalf et.al, 1962). The residual action for DDT under indoor conditions lasts for almost a year, and for Lindane it lasts for several months (Metcalf et.al., 1962), while no data is available on the residual action of Sevin under indoor conditions.

As far as cost is concerned, DDT is cheaper than Lindane or Sevin. On the other hand, Bacon (1960) reported that DDT against G. operculella (Zell.) in the field showed little effect because the moths developed tolerance towards it.

Thus, if potatoes are to be stored as seed potato, DDT at 1 per cent concentration may be used to protect them from G. operculella (Zell.) because of its low cost and lasting residual effect. If potatoes are stored for human consumption, Sevin may be used to protect them against G. operculella (Zell.) because of its lower mammalian toxicity and its more rapid detoxification and elimination from tissues. Because of the higher toxicity of Lindane it is preferable that it not be recommended against G. operculella (Zell.) in storage, unless DDT and Sevin are not available.

CONCLUSIONS AND SUMMARY

Sound potato tubers were bagged in sets of four burlap bags impregnated with water dilutions of one of three insecticides: DDT, Lindane and Sevin, each at two concentrations; one set was left as a control. Thus there was a total of seven treatments, replicated three times. Each replicate consisted of four bags, giving a total of 21 treatments. Each replicate was placed in a separate cage where three adult males and three females of G. operculella (Zell.) were introduced into each cage in order to test the effectiveness of the insecticides in protecting the sound tubers. The three insecticides showed equal effectiveness, by killing 100 per cent of the moths within 48 hours, which resulted in zero per cent infestation of stored tubers, while tubers in the "control" were found severely infested.

Thus, because of the lasting residual effect of DDT, it may be recommended to protect stored seed potato from G. operculella (Zell.) Sevin, which has a lower mammalian toxicity than DDT or Lindane, may

be recommended to protect stored table potatoes. Lindane is equally effective, but has a higher mammalian toxicity than DDT or Sevin, thus it is preferable that it not be recommended against G. operculella (Zell.) unless the other two insecticides are not available.

Storage of tubers in cool, dark cellars will reduce infestation, because it retards the development of this insect; a conclusion which is based on findings in the first part of this thesis (p. 32).

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