THE IMPORTANCE OF PHYCITINES ON IMPORTS TO BRITAIN IN RELATION TO THEIR BIOLOGY

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INTRODUCTION: During the past 35 years, Advisers of the Ministry of Agriculture, Fisheries and Food (MAFF) and the Department of Agriculture and Fisheries for Scotland (DAFS) have been examining cargoes of stored products for insects on arrival in Britain. Information is recorded on the degree of infestation, the species concerned, the country of origin and type of commodity infested. The present paper analyses the records of one particular family of insects on imports to Britain from all over the world for the period 1967-76, during which time nearly 70,000 cargoes were inspected.

The most commonly imported moth is the Tropical Warehouse or Almond moth, *Ephestia cautella* (Walker). It is second only to the Flour beetle, *Tribolium castaneum* (Herbst), both in terms of frequency of import and actual numbers. *E. cautella* belongs to the family Phycitinae which contains the largest number of moth species infesting stored products not only in Britain but throughout the world.

This paper also discusses the pest status of each species in relation to our current knowledge of their biology. In recent years a considerable amount of work has been carried out on the biology of storage Phycitines. All the species described here have been the subject of detailed study at the Pest Infestation Control Laboratory (PICL), England, although currently work is concentrated on *Ephestia cautella*, *Ephestia kuehniella* Zeller, *Ephestia elutella* (Huebner) and *Plodia interpunctella* (Huebner).

Interpretation of records. Records of a particular species on a cargo should be interpreted with some caution but provided the following points are remembered, the records can be a valuable addition to our knowledge of the distribution and pest status of each species

(a) Although an insect found on a cargo arriving in Britain probably came from the country of origin of that cargo, it is possible that it was acquired by cross infestation in the ship during the voyage. Similarly, the finding of a particular species on a foodstuff does not necessarily mean it can complete its life-cycle on that commodity, since it may have strayed onto it from another cargo in the same ship. Cases where this seems likely to account for an unusual occurrence of a species are indicated as such in the tables to follow. Each record should be considered together with what is already known of the insects' biology.

(b) The number of records of a species from a particular zoogeographic region or on a particular commodity may reflect the volume of trade involved and the efficiency of control measures as well as the actual frequency of occurrence of the insect. As far as possible these factors are taken into consideration as each species is described in the present paper. In some of the tables, the number of records are expressed as a percentage of ship inspections carried out. During the period 1972-1975 just over half the tonnage of infestible commodities imported was inspected.

(c) I have used the system of zoogeographic regions adopted by Aitken in her book 'Insect Travellers - Coleoptera' (1). This is based on the natural regions of Jeannel (2) with minor changes to take into account national borders, since MAFF records all relate to individual countries and not usually the particular region in a country.

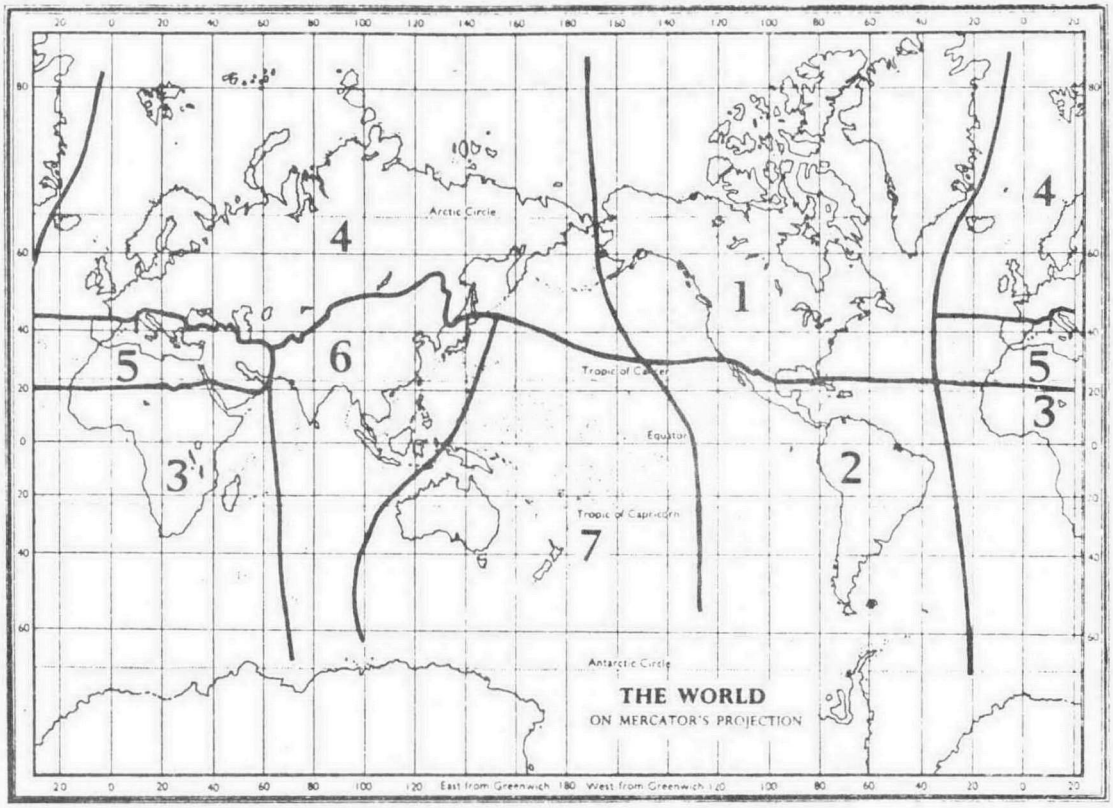

Figure 1. Zoogeographic regions of the world (After Aitken (1)
(1) North America, (2)Central and South America,
(3) Africa, South of the Sahara, (4) Northern Europe,
(5) Mediterranean, (6) Orient, (7) Australasia.

Analysis of infestation by region. The percentage of all cargoes found to be infested by Phycitines over the 10 years was just over 12, and ranged from 24% for Africa, South of the Sahara with over

3800 records, to under 1% for Northern Europe with nearly 30 records (Table 1). In most of the 7 regions, *E. cautella*

Table I. Analysis of infestation by region

Insect	Cargoes infested								
	Amer. North	Amer. C & S	Europe N	Medit-ter.	Africa south	Orient	Austr.	Total	% of insp.
E. cautella	141	656	8	539	3712	2327	455	7838	11
P. interpunctella	93	50	12	194	94	176	14	633	1
E. calidella	-	-	-	46	-	-	-	46	<1
E. kuehniella	13	-	5	4	-	1	15	38	<1
E. elutella	1	1?	3	12	5?	2?	6	30	<1
E. figulilella	-	-	-	6	1?	-	-	7	<1
E. ceratoniae	-	-	-	3	-	-	-	3	<1
TOTAL ALL SPECIES	248	707	28	804	3812	2506	490	8595	
(as % of inspections)	2	15	<1	10	24	17	8	12	

? Origin of infestations doubtful.

accounted for by far the largest number of records, followed by *P. interpunctella*, the exception being in cargoes from Northern Europe where the order of these 2 species was reversed. The total number of records from all regions was just over 7800 for

E. cautella and 600 for *P. interpunctella*, while *Ephestia calidella* Guenée, *E. kuehniella* and *E. elutella* had between 50 and 30 records each. *Ephestia figulilella* Gregson and *Ectomyelois ceratoniae* (Zeller) had less than 10 records each.

The Mediterranean was the only region with records of all 7 species, and 2 of the species, *E. calidella* and *Ectomyelois ceratoniae*, were only found on cargoes from this region. *E. figulilella* also belongs to this category because the record of this species from Africa is unconfirmed. *E. cautella*, *E. elutella* and *P. interpunctella* were recorded from all 7 regions, although *E. elutella* is not endemic in most parts of South America, Africa, and the Orient, and so infestations of this species on cargoes from these regions are of doubtful origin. *E. kuehniella* was detected on cargoes from all regions except Africa, South of the Sahara, and Central/South America.

It is generally believed that *Ephestia* spp. and *Ectomyelois ceratoniae* are of Mediterranean origin, with *Plodia* probably from the Americas (3). However, with the exception of *E. calidella*, *E. figulilella* and *Ectomyelois ceratoniae*, the other 4 species are virtually cosmopolitan in distribution through world trade.

Sinha has proposed a climatic plasticity index as a measure of the ability of each species to adapt to various climatic zones, based on the integration of physical limits data and intrinsic rates of increase (3). Using this index for the Phycitines, in order of decreasing adaptability, the species are *E. kuehniella* (600), *E. cautella* (575), *P. interpunctella* (330), *E. calidella* (230), *E. elutella* (165). Indexes for *E. figulilella* and *Ectomyelois ceratoniae* are not given by Sinha but, based on data from Cox (5, 6) and unpublished data, they would probably be at the lower end of the scale near *E. elutella*. It is interesting to note that, apart from *E. kuehniella*, this order is the same as that for the number of records of each species on imports to Britain from all over the world. *E. kuehniella* is not at the top of this list probably because it can thrive only on a much narrower range of foodstuffs than *E. cautella*, the former mainly being confined to cereal and cereal products. Furthermore, these commodities are generally imported from regions, such as North America, with low levels of infestation of all insects on imports.

Analysis of infestation by commodity. Commodity groups chosen for table II are those with the higher levels of infestation. The table also demonstrates the success of *E. cautella* on stored products, in that at least 4% of all cargoes inspected in each commodity group were infested with this species. Commodity groups with the highest number of records of *E. cautella* were oilseeds and products and cocoa beans and products, each with nearly 40% of cargoes inspected being infested.

Plodia was also recorded on all commodity groups but this species only reaches a maximum infestation level of 3%, on nuts. *E. elutella*, whilst infesting all the major groups, never

Table II. Analysis of infestation by commodity

Insect	Cargoes infested							
	Oilseeds and products	Cereals and products	Cocoa beans/ products	Nuts	Dried fruit	Pulses/ products	Carobs/ products	Others
E. cautella	3665	1011	919	546	247	300	116	1034
P. interpunctella	132	141	6	167	104	9	8	66
E. calidella	1?	-	-	7	1	1	35	1
E. kuehniella	-	31	-	1	-	6	-	-
E. elutella	1?	9	4	1	7	1	1	6
E. figulilella	1?	-	-	-	3	-	3	-
E. ceratoniae	-	-	-	2	-	-	1	-
Total all species	3799	1192	929	724	362	317	164	1107
(As % of inspections)	40	6	40	13	6	7	36	5

? Doubtful records.

reached the 1% level of infestation and the record on oilseed was doubtful. Oilseeds and products and cocoa beans and their products were the most frequently infested commodities, with 40% of cargoes examined being infested by one or more species of Phycitine. Carobs and carob products were the next most frequently infested commodities (36%), with *E. cautella* accounting for 26% and *E. calidella* 8%. Thirteen percent of nuts were infested with *E. cautella* and *Plodia*, and 6% of dried fruit cargoes.

Changes in annual rates of infestation. Table III shows how the

Table III. Frequency of infestation by *Ephestia cautella*

	Total No. records per 100 inspections					
	1967-8	1969-70	1971-2	1973-4	1975-6	10-year mean
Africa (S. of Sahara)	34	26	22	19	17	23
Orient	15	17	16	16	14	15
America (C and S)	14	13	12	14	17	14
Australasia	6	8	6	9	11	8
Mediterranean	7	7	4	5	5	5
America (N)	2	<1	<1	1	1	1
Europe (N)	<1	-	<1	<1	<1	<1
Total all regions	2145	1828	1507	1291	1067	
As % of inspections	15	13	10	10	9	

level of infestation of *E. cautella*, the most frequently recorded species1, has altered over the 10 year period. There has been a steady fall in the % of cargoes infested, from 15 in 1967-8 down to 9 by 1975-6. Most of this reduction is due to a fall from 34% to 17% in the cargoes infested from Africa, South of the Sahara. There was no significant change in infestation levels for the other species, except for *P. interpunctella* which fell from 6% to 1% in cargoes from the Mediterranean region.

The importance of each species on imports will now be considered in relation to our knowledge of their biology.

Ephestia cautella. This species is able to develop on a remarkably wide range of stored products, being a pest of cereals, oilseeds, cocoa, nuts, dried fruit, carobs, and their products (Table IV). Whole cereals and soybeans are poor foods for this

Table IV. Records of *Ephestia cautella* on imports

	No. records all regions	Region with largest No. cargoes infested
Oilseeds, Oilseed products	3665	Africa, S. of Sahara
Grain, Grain products	1011	Orient
Cocoa beans, Cocoa bean products	919	Africa, S. of Sahara
Nuts	546	Orient
Pulses, Pulse products	300	Africa, S. of Sahara
Dried fruit	247	Mediterranean
Carobs, Carob products	116	Mediterranean
Others	1034	Orient

species, presumably the hard seed coat preventing penetration by larvae (7). Larvae are unable to develop at all on whole black grams and lentils, although grinding up these foods greatly improves their suitability (8).

E. cautella has spread throughout the world by trade although it is basically a species of warm, tropical countries. It requires a minimum of 15°C for complete development (9) and 17°C for annual doubling of numbers (10). It can, however, breed in warehouses in temperate climates during the summer, although mortality may be heavy in winter (11). Mathlein (12) has shown it to be much less cold tolerant than *E. elutella* and *E. kuehniella* in Sweden. It is also able to establish itself in heated premises, such as the spillage inside machinery and sample rooms of food-processing factories (13). Upper limits for development are about 36°C, development being fastest at 30-32°C, and 70-80% R.H. (9). Limiting humidities are about 20% and above 90% R.H.

Plodia interpunctella. *Plodia*, like the previous species, has a wide host range but is particularly troublesome on dried fruit, grain products and nuts (Table V). It also develops well on whole grains such as wheat (14).

This species is an important pest of stored food products in most parts of the world, although it is basically an insect of warmer climates. It requires a minimum of 18°C for annual doubling of numbers, and has a range of 28-32°C for optimum development, similar to *E. cautella* (10). It occurs sporadically in warehouses in temperate climates (14). *Plodia* is slightly

Table V. Records of *Plodia interpunctella* on imports

	No. records all regions	Region with largest No. cargoes infested
Nuts	167	Mediterranean
Oilseed, Oilseed products	132	Africa, S. of Sahara
Grain, Grain products	141	America, N.
Dried fruit	104	Mediterranean
Pulses pulse products	9	Africa, S. of Sahara
Carobs, Carob products	8	Mediterranean
Cocoa beans, Cocoa bean products	6	Orient
Others	66	Orient

more cold tolerant than *E. cautella*, being able to survive some winters in grain silos in Southern England (15). The minimum R.H. permitting complete development is around 25% R.H. (16).

Ephestia kuehniella. *E. kuehniella* is the major pest of flour mills in countries of temperate climate. This species is also known in many other parts of the world where it has been spread through trade. However, it is rarely recorded from India, the Far East apart from Japan, and some parts of Africa where it appears to be replaced in flour mills by *E. cautella* and *Corcyra cephalonica* Stainton (17). On imports to Britain it is mainly confined to those from Australasia, N. America and N. Europe (Table VI). Laboratory studies have shown that for complete development, lower limits are around 10°C and near 0% R.H., and upper limits near 30°C and above 75% R.H. (18). Infertility of adults at 30°C prevents a second generation being established at this temperature (16). Thus, the temperature requirements of *E. kuehniella* probably account in part for its absence on imports from Central and South America, much of Africa and the Orient. It is also restricted in its spread by a limited ability to develop on different foods, being confined mainly to cereals and cereal products. Although development has been demonstrated in the laboratory on cocoa beans, dried fruit, nuts and pulse products, it is much slower with lower survival than on cereals. Table VII records the ability of each species to develop on the major types of stored foodstuff, based on laboratory data from a number of sources including our own work at PICL.

Table VI. Records of *Ephestia kuehniella* on imports

	No. records all regions	Largest number cargoes infested
Wheat, wheat products	17	America, N.
Maize, maize products	6	Europe, N. America N.
Rice	5	Mediterranean
Other grains	3	Australasia
Peas, pea products	6	Australasia
Gallnuts	1	Orient

Table VII. Ability to develop on various commodities, mainly based on published laboratory data

	Cereal/ prod.	Soya bean/ prod.	Cocoa bean/ prod.	Nuts	Dried fruit	Pulses/ prod.	Carob/ prod.
E. caut.	Y(9)	Y(34)	Y (9)	Y(24)	Y(24)	Y(8	Y(24)
P. inter.	Y(14)	Y(34)	Y(36)	Y(14)	Y(14)	Y(37)	Y(*)
E. calid.	Y(32)	?	?	Y(24)	Y(24)	?	Y(24)
E. kuehn.	Y(19)	X(34)	X(36)	X(*)	X(20)	X(20)	X(*)
E. elut.	Y(35)	Y(34)	Y(35)	Y(38)	Y(35)	Y(35)	Y(*)
E. fig.	Y(32)	X(*)	X(*)	Y(24)	Y(24)	Y(*)	Y(24)
E. cera.	?	Y(39)	?	Y(27)	Y(32)	?	Y(32)

Y: Able to develop from egg hatch to adult emergence, with good survival.

X: Unable to complete development or only very slowly and with poor survival.

?: No laboratory data available.

(): Numbers refer to references at end of paper.

(*): Unpublished data from recent work at PICL.

Fraenkel and Blewett suggested that part of this species' success on cereal products such as flour was due to its relative insensitivity to lack of riboflavin in low extraction flour (19). Furthermore, *E. kuehniella* can develop equally well on starch and glucose, unlike other Phycitines. It appears to feed indiscriminately on germ and endosperm of whole grain, although first

instar larvae can only feed on whole grain when it is damaged (20). This may be a factor in the lower incidence of this species on whole grain than on cereal products.

The ability of *E. kuehniella* to develop at exceptionally low moisture content/R.H. is probably another reason for its success in flour mills, and hence its abundance on imports of milled cereal products.

Ephestia elutella. *E. elutella* is found on cereal products less frequently than *E. kuehniella* but is able to develop on a wider range of foodstuffs than the latter species (Table VIII). Both

Table VIII. Records of *Ephestia elutella* on imports

	No. records all regions	Region with largest No. cargoes infested
Grain, grain products	9	Australasia
Dried fruit	7	Mediterranean
Cocoa beans	4	Europe, N. (trans-America, N. shipped)
Nuts	1	Mediterranean
Carobs	1	Mediterranean
Peas	1	Europe, N.
Others	7	Mediterranean

facts are reflected in their incidence on imports: 31 and 9 records on cereal and cereal products for *E. kuehniella* and *E. elutella* respectively, but records on 2 and 6 other main commodity groups respectively, although the record of *E. elutella* on oilseed is doubtful. *E. elutella* is also the only storage moth to be found regularly on tobacco.

This species does not develop very well on low extraction or even whole meal flour (19). On whole grain, only the embryo is eaten, leaving the endosperm untouched, unlike *E. kuehniella* which eats both.

Although both species have been spread throughout the world by trade, *E. elutella* is essentially a species of temperate climate where it can be a serious pest on whole grain kept in store for several years(21). Its infrequent appearance on imports probably reflects its comparative lack of success in establishing itself in the more tropical regions. Furthermore, vigorous control measures in N. America and other temperate regions, together with the short storage periods of grain before export, have considerably reduced its occurrence on imports from these areas in recent years.

In the past, *E. elutella* has been frequently confused with *E. cautella*. Thus, early records in the scientific literature of the former species are of doubtful value in establishing its world distribution and ability to attack particular products.

The small number of laboratory studies conducted on this species have shown that it can complete development at 15°C but not at 10°C (16). Individual developmental stages are able to survive much lower temperatures than this, however. At 30°C, although development is completed, only a few of the adults bred at this temperature are able to produce a second generation. Development is completed at humidities as low as 25% R.H. at both 15°C and 30°C.

Ephestia figulilella and *E. calidella*. The greater frequency of *E. calidella* than *E. figulilella* on imports (Table IX) reflects a

Table IX. Records of *Ephestia calidella* and *Ephestia figulilella* on imports; all records from Mediterranean

	E. calidella	*E. figulilella*
Carobs, carob products	35	3
Nuts	8	-
Dried fruit	1	3
Others	2	1?

? Doubtful record on sunflower seed from Malawi.

similar pattern of infestation found in warehouses, such as carob stored in Cyprus (22). Thus, *E. figulilella* is usually less of a storage pest than *E. calidella*, the former being commonly associated with fallen fruit, freshly harvested carobs and other crops, and in some areas attacking ripe dates still on the tree. *E. calidella* on the other hand, while still capable of attacking appropriate crops before harvest, is commonly found in stores on dried fruit and carobs. Both species have a winter larval diapause partly controlled by daylength but in *E. calidella* diapause is weaker than in *E. figulilella* (23). This may further reflect the stronger affinity of *E. figulilella* for the pre-harvest field situation and the greater ability of *E. calidella* to exploit the storage environment.

On a semi-artificial diet, the lower limit for complete development of both species is between 50% and 30% R.H. (5),

whereas on a similar diet *E. cautella* can develop down to about 20% R. H. (9). Presumably the drier conditions and lower moisture content of products in storage, in contrast to their pre-harvest field condition, are less suitable for the development of *E. figulilella* and *E. calidella* than *E. cautella*. The temperature limits for *E. cautella*, *E. calidella* and *E. figulilella* are very similar, being 36°C and 15°C. However, the range of products which can support complete development of *E. cautella* is much greater than for the other two species (Table VII). Development of *E. cautella* on almonds is considerably faster and survival higher than in *E. figulilella* and *E. calidella* (24), *E. cautella* being the commonest insect on almonds imported to Britain (25).

In laboratory tests on almonds in California, *E. cautella* was a stronger competitor in mixed populations than *E. figulilella*, due in part to variation in egg viability and possibly egg predation (26). This may be another factor in the lower numbers of the latter species in stores where other species are also present.

Ectomyelois ceratoniae. *E. ceratoniae* differs from the other Phycitines on imports in regularly attacking some products in the field prior to harvest, especially citrus fruit and carobs (27). it can also be a serious pest of almonds and carobs in stores after harvest, mainly in the Mediterranean region (28, 29). It has been shown that attack by this species predisposes carobs to attack by *Ephestia cautella* and other storage pests (30). It is apparently unable to complete more than one generation in stores. Unlike other storage Phycitines, cereal products are a poor food for *E. ceratoniae* and this severely limits its frequency on imports. It is not surprising therefore that it is the least common Phycitine on imports to Britain, being recorded only 3 times in 10 years, twice on almonds and once on carobs from the Mediterranean. Its spread within a store or cargo is further limited by the lack of a larval wandering period prior to pupation, a density regulating mechanism useful in the confined spaces of a store or ship's hold. (6). Other aspects of its behaviour that may hinder the development of *E. ceratoniae* in stores include the requirement for fluctuating light, temperature and humidity field conditions before adults will mate and lay fertile eggs. Furthermore, unlike other Phycitines, this species will not mate in confined spaces (6).

Mussidia nigrivenella. *Mussidia nigrivenella* Ragonot was not recorded during the period of the current survey but it is another Phycitine which has been imported on produce from West Africa in the past. It is the main storage pest of maize in Nigeria, Ghana and Togo, attacking mature but undried grains on the cob (4). This species also attacks cocoa beans, calabar and butter beans.

Diapause in storage Phycitines. Some strains of all seven species have been shown to exhibit diapause, expressed as a delay in

development of fully mature larvae enabling them to survive adverse conditions such as low temperature, food shortage or stress imposed by toxicants. Diapause may also synchronise adult emergence to ensure successful reproduction in a favourable environment. The ability to enter diapause and the particular conditions of temperature and daylength controlling it, will help to determine whether a species exported from one region can successfully colonise another region of the world.

The importance of factors such as temperature and photoperiod in controlling diapause in *P. interpunctella* and *E. elutella* (31), *E. calidella*, *E. figulilella* and *E. ceratoniae* (32, 23) have been studied at PICL, England, in recent years. Diapause is to some extent photoperiodically controlled and is stimulated by temperatures near to the developmental minimum. Termination of diapause and synchronisation of post-diapause emergence is hastened by exposure to low temperatures for long periods. The more recently discovered diapause in some strains of *E. cautella* (33) and *E. kuehniella* (18) are the subject of work currently in progress at PICL.

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