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Stored-food product insects and their relationship to packaging problems

Landrock, Arthur Harold

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Thesis

STORED-FOOD PRODUCT INSECTS
AND
THEIR RELATIONSHIP TO PACKAGING PROBLEMS

by

ARTHUR HAROLD LANDROCK
(B.S., Queens College, 1941)

Submitted in partial fulfilment of the
requirements for the degree of
Master of Arts
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Approved by

First Reader

[Signature]
Assistant Professor of Biology

Second Reader

[Signature]
Assistant Professor of Biology
# LIST OF PLATES AND FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 -</td>
<td>Section through thin-walled type of sensillum on antenna of <em>Rhodnius</em></td>
<td>123</td>
</tr>
<tr>
<td>2 -</td>
<td>Surface view of part of an antennal segment in <em>Rhodnius</em></td>
<td>123</td>
</tr>
<tr>
<td>3 -</td>
<td>Detail of olfactory pit showing sensory rods each supplied by a single sense cell</td>
<td>123</td>
</tr>
<tr>
<td>4 -</td>
<td>Longitudinal section of top of labial palp of <em>Pieris rapae</em> showing pit containing olfactory rods</td>
<td>124</td>
</tr>
<tr>
<td>5 -</td>
<td>Sensilla on antenna of <em>Apis</em></td>
<td>124</td>
</tr>
<tr>
<td>6 -</td>
<td>Typical Cucujid larvae, ventral and dorsal views, with enlarged view of mouthparts</td>
<td>125</td>
</tr>
<tr>
<td>7 -</td>
<td>Yellow mealworms, <em>Tenebrio molitor</em> L. (photographs)</td>
<td>126</td>
</tr>
<tr>
<td>8 -</td>
<td>Yellow mealworm, <em>Tenebrio molitor</em>, all stages (drawing)</td>
<td>127</td>
</tr>
<tr>
<td>9 -</td>
<td>Dark mealworm, <em>Tenebrio obscurus</em> F., pupa, ventral view</td>
<td>127</td>
</tr>
<tr>
<td>10 -</td>
<td>Dark mealworm, <em>Tenebrio obscurus</em> F., pupa</td>
<td>130</td>
</tr>
<tr>
<td>11 -</td>
<td>Adult of <em>Tenebrio molitor</em> L.</td>
<td>130</td>
</tr>
<tr>
<td>12 -</td>
<td>Larva of the furniture carpet beetle, <em>Anthrenus vorax</em> Waterhouse, ventral view</td>
<td>131</td>
</tr>
<tr>
<td>13 -</td>
<td>Adult of <em>Anthrenus vorax</em> Waterhouse, dorsal and ventral views.</td>
<td>131</td>
</tr>
<tr>
<td>14 -</td>
<td>Common carpet beetle, <em>Anthrenus scrophulariae</em>, all stages (drawing)</td>
<td>132</td>
</tr>
<tr>
<td>15 -</td>
<td>Larder beetle, <em>Dermestes lardarius</em>, all stages (drawing)</td>
<td>132</td>
</tr>
</tbody>
</table>
16 - Hide beetle, *Dermestes maculatus* De Geer 133
Dried-fruit beetle, *Carpophilus hemipterus* (L) 133
Saw-toothed grain beetle, *Oryzaephilus surinamensis* 133

17 - Red-legged ham beetle, *Necrobia rufipes*, all stages (drawing) 133

18 - Silphids (beetles of the family Silphidae) 134

19 - Broad-horned flour beetle, *Gnathocerus cornutus* (F.) 134

20 - Saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) 135

21 - Cigarette beetle, *Lasioderma serricorne*, all stages (drawing) 135

22 - Drugstore beetle, *Sitodrepa panicea*, all stages (drawing) 136

23 - Flat grain beetle, *Laemophloeus pusillus* 136

24 - Rust-red grain beetle, *Laemophloeus ferrugineus* (Stephens) 137

25 - *Alphaneotus destructor*, adults and larvae, and a carton showing the damage wrought by this insect 137

26 - Rice weevil, *Sitophilus oryzae* (L.) 138

27 - Granary weevil, *Sitophilus granarius* 138

28 - Confused flour beetle, *Tribolium confusum*, all stages (drawing) 139

29 - The confused flour beetle, *Tribolium confusum* Jacq. Duval, larva and adults 139

30 - The cadelle, *Tenebroides mauritanicus* (L.), all stages (drawing) 140
31 - Living adults of the caddelle, dorsal and ventral views ... 140

32 - Various views of an Elateriid beetle, probably closely related to package-infesting insects ... 141

33 - Lesser grain borer, Rhizopertha dominica. This is one of the test insects called for in the TAPPI Tentative Standard T 475 m-47 ... 141

34 - Common termite, Reticulotermes flavipes ... 142

35 - Embiid - Oligotoma saundersii. Psocid - Psocous confratermus. Common booklouse - Liposcelis divinatorius ... 142

36 - European earwig, Forficula auricularia ... 143

37 - A Gryllid (cricket), one of the few Orthoptera that are food pests. Species unidentified ... 143

38 - A large black ant, probably a carpenter ant. Found in the field under bark. Several views ... 144

39 - Silverfish, Lepisma saccharina ... 145

40 - Labium of Thermobia domestica ... 145

41 - A common mite (Tyroglyphus sp.) ... 146

42 - Mediterranean flour moth, Ephestia kuehniella Zeller ... 146

43 - Indian meal moth, Plodia interpunctella ... 147

44 - Angoumois grain moth, Sitotroga cerealella ... 147

45 - Case-making clothes moth, Tinea pellionella, all stages (drawing) ... 148

46 - Eggs of broad-horned flour beetle, caddelle, Mediterranean flour moth, and confused flour beetle on TOPX cloth ... 148
<table>
<thead>
<tr>
<th>Page</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>47</td>
<td>Eggs of important mill insects on various mesh bolting cloths</td>
</tr>
<tr>
<td>48</td>
<td>Day-old larvae of a number of mill insects resting on bolting cloth just fine enough to remove them from flour</td>
</tr>
<tr>
<td>49</td>
<td>Excreta</td>
</tr>
<tr>
<td>50</td>
<td>A cake flour package showing typical tight-wrap construction</td>
</tr>
<tr>
<td>51</td>
<td>A package for dehydrated soup mix constructed with glued top flaps</td>
</tr>
<tr>
<td>52</td>
<td>A metal can for dehydrated materials, such as the dehydrated ice cream mix in this can, represents the ultimate in protection against insect infestation</td>
</tr>
<tr>
<td>53</td>
<td>Holes bored in the lead sheathing of aerial cables by the California lead cable borer (Scobica declivis Leo.)</td>
</tr>
<tr>
<td>54</td>
<td>Test units used by Chamberlain and Hoskins</td>
</tr>
<tr>
<td>55</td>
<td>Crystallizing dish test unit used in this thesis</td>
</tr>
<tr>
<td>56</td>
<td>Shell beans attacked by bean weevils (Acanthoscelides obtectus (Say)), showing the insects still in the holes</td>
</tr>
<tr>
<td>57</td>
<td>Cadelles eating their way through corn kernels</td>
</tr>
<tr>
<td>58</td>
<td>Examples of penetrations in the crystallizing dish test</td>
</tr>
<tr>
<td>59</td>
<td>Polyethylene bag made from seamless tubing and used in later testing, showing corner chewed off by mealworms</td>
</tr>
<tr>
<td>60</td>
<td>A bag made for testing from polyethylene-coated kraft paper by heat sealing</td>
</tr>
<tr>
<td>61</td>
<td>Mason jar assembly used in later testing</td>
</tr>
<tr>
<td>62</td>
<td>The Mason jar assembly as used in actual testing. Some results of penetrations through tissue paper and onion skin paper</td>
</tr>
</tbody>
</table>
63 - Diagram showing hypognathous type of head
structure ........................................ 159
64 - Diagram showing prognathous type of head
structure ........................................ 159
65 - Diagrams showing the general structure of an in-
sect's head and the relations of the mouthparts
to the cranium. Lateral and transverse sections. 160
66 - Diagram of the structure and musculature of the
first maxilla of an insect ....................... 161
67 - Head of *Tinea pallescens* Staint. showing
long and filiform maxillary palpi .............. 162
68 - Head of *Tineola bisselliella* (Hummel) showing
short and inconspicuous maxillary palpi ....... 162
69 - Diagram of typical apterygote mandibles ........ 163
70 - Diagram of typical pterygote mandibles ........ 163
71 - Diagram of the structure and mechanism of an in-
sect mandible that serves as a biting and
chewing jaw ........................................ 164
72 - Percentages of different species of insects taken
in mill streams of flour mills .................. 164
73 - Biotic constants for the duration of various
stages in the life of *Tribolium confusum* at
75% relative humidity ............................ 165
74 - Moisture equilibria of typical stored food
products ............................................. 166
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>II. Olfaction and Taste</td>
<td>8</td>
</tr>
<tr>
<td>III. Food Procurement</td>
<td>13</td>
</tr>
<tr>
<td>IV. Insects and Their Relationship to Packages containing Food</td>
<td>23</td>
</tr>
<tr>
<td>V. Descriptions and Discussions of the More Important Stored-Food Product Insects</td>
<td>42</td>
</tr>
<tr>
<td>A. Order ACARINA (of Class Arachnida)</td>
<td></td>
</tr>
<tr>
<td>Tyrophagus farinae De Geer</td>
<td>42</td>
</tr>
<tr>
<td>B. Order THYSANURA</td>
<td></td>
</tr>
<tr>
<td>Lepisma saccharina L.</td>
<td>43</td>
</tr>
<tr>
<td>C. Order ORTHOPTERA</td>
<td></td>
</tr>
<tr>
<td>Blatta orientalis L.</td>
<td>44</td>
</tr>
<tr>
<td>D. Order ISOPTERA</td>
<td></td>
</tr>
<tr>
<td>Reticulotermes flavipes</td>
<td>46</td>
</tr>
<tr>
<td>E. Order CORRODENTIA (=PSOCOPTERA)</td>
<td></td>
</tr>
<tr>
<td>Troctes divinatoria Mull.</td>
<td>48</td>
</tr>
<tr>
<td>F. Order LEPIDOPTERA</td>
<td></td>
</tr>
<tr>
<td>Ethesia seriaria (Scott)</td>
<td>49</td>
</tr>
<tr>
<td>Plodia interpunctella (Hübner)</td>
<td>51</td>
</tr>
<tr>
<td>Sitotroga cerealella (Olivier)</td>
<td>54</td>
</tr>
<tr>
<td>G. Order COLEOPTERA</td>
<td></td>
</tr>
<tr>
<td>Acanthoscelides obtectus (Say)</td>
<td>56</td>
</tr>
<tr>
<td>Carpophilus hemipterus (L.)</td>
<td>58</td>
</tr>
<tr>
<td>Derestes ater De Geer</td>
<td>59</td>
</tr>
<tr>
<td>Derestes lardarius (L.)</td>
<td>61</td>
</tr>
<tr>
<td>Derestes maculatus De Geer</td>
<td>62</td>
</tr>
<tr>
<td>Graphoderus cornutus (Fab.)</td>
<td>63</td>
</tr>
<tr>
<td>Laemophloeus ferrugineus</td>
<td>64</td>
</tr>
<tr>
<td>Laemophloeus minutus (Olivier)</td>
<td>65</td>
</tr>
<tr>
<td>Laemophloeus turcicus Grouvelle</td>
<td>66</td>
</tr>
<tr>
<td>Lasioderma serricoine (Fab.)</td>
<td>66</td>
</tr>
<tr>
<td>Necrobia rufipes De Geer</td>
<td>68</td>
</tr>
<tr>
<td>Oryzaephilus surinamensis (L.)</td>
<td>70</td>
</tr>
<tr>
<td>Ptinus fur (L.)</td>
<td>72</td>
</tr>
</tbody>
</table>
### TABLE OF CONTENTS

V. Descriptions and Discussions of the More Important Stored-Food Product Insects (cont'd.)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>G. Order COLEOPTERA (cont'd.)</td>
<td></td>
</tr>
<tr>
<td><em>Ptinus ocellus</em> Brown</td>
<td>73</td>
</tr>
<tr>
<td><em>Rhizopertha dominica</em> (Fab.)</td>
<td>74</td>
</tr>
<tr>
<td><em>Sitodrepa panicea</em> (L.)</td>
<td>77</td>
</tr>
<tr>
<td><em>Sitophilus granarius</em> (L.)</td>
<td>79</td>
</tr>
<tr>
<td><em>Sitophilus oryzae</em> (L.)</td>
<td>79</td>
</tr>
<tr>
<td><em>Tenebrio molitor</em> (L.)</td>
<td>85</td>
</tr>
<tr>
<td><em>Tenebrio obscurus</em> (Fab.)</td>
<td>85</td>
</tr>
<tr>
<td><em>Tenebroids mauritanicus</em> (L.)</td>
<td>86</td>
</tr>
<tr>
<td><em>Trybolium castaneum</em> (Herbst)</td>
<td>91</td>
</tr>
<tr>
<td><em>Trybolium confusum</em> Jacq. Duval</td>
<td>92</td>
</tr>
</tbody>
</table>

| H. Order HYMENOPTERA                        |      |
| *Monomorium destructor*                     | 95   |

| I. Order DIPTERA                            |      |
| *Platyphe casei* (L.)                       | 96   |

VI. Experimental Work                        | 97   |

VII. Results                                 | 101  |

VIII. Discussion                             | 104  |

IX. Conclusions                              | 106  |

X. Recommendations for Further Work          | 107  |

XI. Remarks                                  | 108  |

XII. Appendix                                | 109  |

A. Systematic List of Insects and Other Arthropods Infesting Foods and Food Products | 109  |

B. Stored-Food Product Coleoptera Arranged Phylogenetically According to Super-families and Families | 120  |

C. Plates and Figures                        | 121  |

   (including T.A.P.P.I. Standard)             |

XIII. Bibliography                           | 168  |

XIV. Abstract                                | 177  |
I. INTRODUCTION

This thesis has been written in an attempt to provide the food packaging technologist with as much background as possible to enable him to understand the biological principles involved in insect infestations of food packages. It is hoped that, in addition to principles, he will find sufficient factual information on almost any type of insect he is likely to encounter, to assist him in the control of these insects. An effort has been made to provide the reader with enough illustrative material to obviate the necessity of searching through many references to find what the more common package-infesting insects look like.

The packaging industry is a tremendous one. That portion of the industry concerned with food packaging is especially large, for the food industry itself is the largest in the country today. The housewife has come to demand packaged foods for several reasons. She is assured of purer foods because of the lesser amount of direct handling; she knows that the reputation of the food packer stands behind the label; she finds packaged foods much more convenient to handle. These are but a few of the more important advantages of packaging foods. But along with these advantages the manufacturer has increased responsibilities. He must be extremely careful to deliver his goods to the consumer in top-quality condition. If he
fails, he will not be in business very long. One of the 
surest ways for him to annoy the housewife is for him to 
present her with packages infested with insects. Whether 
these insects developed from eggs already in the food when 
packaged, or whether they entered the package through 
faulty package construction matters little. Fortunately 
most reputable manufacturers are doing everything they can 
to deliver insect-free packages to their customers. The 
author is in a position to observe the tremendous inter­
est in prevention of insect infestation throughout the 
packaging industry today. This industry is trying to do as 
good a job as possible with the money it has to spend. 
Fortunately, but in some respects unfortunately, the food 
industry is highly competitive, and margins of profit are 
very small. This fact makes the average manufacturer 
think twice before he spends money on improving his 
packages for any reason whatever. Someone is going to 
have to pay the extra cost. If the consumer is going to 
be asked to share all or part of this cost, she is going 
to have to be convinced that she is getting something 
extra that is really worthwhile.

The author has deliberately chosen to avoid the sub­
ject of repellents as applied to packaging materials. The 
subject is a complex one and extremely interesting. The 
methods of chemical control have also not been treated,
for it was felt that much helpful material has already been written on this subject.

During the war a great deal of valuable work was done on determining the resistance of heavy boards, laminates, and multi-wall materials in general to penetration by insects. This interest was natural because of the desire of all agencies to see that cartons of food were delivered to troops in all theaters in sound condition. The Quartermaster Corps sponsored a considerable amount of this work. The author felt that for the purposes of this thesis he would like to concentrate on thinner materials, especially the commonly used plastic films, including cellophane, materials more commonly used under normal circumstances. He also desired to study the boring efficacy of several types of insects with a view possibly to adopting them as test insects.

It was felt that there was a definite need for a complete list of all insects attacking stored-food products in this country. This list is much more useful when it groups the insects according to biological subdivisions, especially orders and families. Accordingly considerable time and effort were spent in preparing such a list. For this purpose, Blake's monumental work (1943) was especially helpful. Unfortunately this book does not supply the names of the authors who originally described these insects.
The U.S.D.A. Farmer's Bulletin 1260 was also extremely helpful. Many other sources were consulted, and these have all been acknowledged in the bibliography.

A glance at Table 1 (Types of Insects Attacking Stored Foods) shows that of all the 904 insect species attacking stored foods, the order Coleoptera (beetles) has by far the largest representation (542), with the order Lepidoptera next (175). Accordingly the Coleoptera have been stressed in this thesis. Twenty-two beetle families account for the beetles attacking stored foods in this country. Some 239 insects of all orders are listed as stored-foods pests in the United States. As far as possible the full and most authentic scientific name of each of these forms is listed, along with the name of the man who first described the species. Unfortunately in the orders other than the Coleoptera the describer's name could not always be found without going through a great many sources. Since this would have required a great deal of time, the names have frequently been omitted. In every case, however, some effort was made to locate the name.

In the Coleoptera practically all names are complete. Leng's catalog (1920) and supplements were regarded as the final authority for this order. In cases where the name usually found in the economic literature differs from the taxonomically correct name, both names are given so that the reader may be able to recognize the insect for which he is looking.
<table>
<thead>
<tr>
<th>TYPE</th>
<th>ORDER</th>
<th>GRAMS</th>
<th>MEAT AND FISH (DRIED)</th>
<th>MEAT AND FISH (FRESH)</th>
<th>PEAS, BEANS &amp; LENTILS</th>
<th>PEANUTS</th>
<th>OTHER LEGUMES</th>
<th>EDIBLES</th>
<th>CACAO</th>
<th>RAISINS</th>
<th>DATES</th>
<th>COPRA</th>
<th>OTHER DRIED FRUITS</th>
<th>OTHER MUSCULANAS</th>
<th>SEEDS</th>
<th>DRIED VEGETABLES</th>
<th>FRESH POTATOES</th>
<th>SPICES, CONDIMENTS, ETC.</th>
<th>OILS, FATS &amp; WAXES (LEAD OR NOT)</th>
<th>DRIED EGGS</th>
<th>DRIED MILK</th>
<th>CHEESE</th>
<th>CHOCOLATE</th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SILVERFISH</td>
<td>THYSANURA</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>CRICKETS</td>
<td>ORTHOPTERA</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>2</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>64</td>
<td></td>
<td></td>
<td></td>
<td>63.6</td>
</tr>
<tr>
<td>ROACHES</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td>1</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>58.10</td>
</tr>
<tr>
<td>TERMITES</td>
<td>ISOPTERA</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
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<td>3</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>EARWIGS</td>
<td>DERMAPTERA</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>EMBIDS</td>
<td>EMBIOPTERA</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
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<td>1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>BOOKLICE</td>
<td>PSOCOPTERA</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>MOTHS</td>
<td>LEPIDOPTERA</td>
<td>39</td>
<td>2</td>
<td>2</td>
<td>10</td>
<td>6</td>
<td>7</td>
<td>13</td>
<td>9</td>
<td>9</td>
<td>12</td>
<td>3</td>
<td>22</td>
<td>18</td>
<td>9</td>
<td>6</td>
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SUMMARY TABLE 1

1 of which are MYLABRIDAE
2
3

TYPES OF INSECTS ATTACKING STORED FOODS
(after Blake)

TABLE 1
Wherever possible common names are provided as well as scientific names. In spite of the confusion that inevitably results from their use, the reader must remember that they are used by people in the food industry. In all cases an attempt has been made to place the most frequently used common name before other alternate names.

In the course of reading this thesis, the reader will note frequent references to optimum relative humidities for various insects. In order to provide a ready reference, a plot has been drawn of the moisture and humidity equilibria at 25°C of typical stored foods (Fig. 74).

It will be noted that the slopes of all these curves are about the same. The primary difference between individual product curves lies in the initial moisture contents.

For the convenience of the reader who may wish to learn details of the biting mechanism of stored-food insects, a considerable amount of material on mouthpart structure has been presented in the text and in the form of line drawings in the Appendix. The drawings are largely from Snodgrass (1931, 1944) from whose works they have been traced directly. However, the liberty has been taken of placing labels directly on the figures rather than using code letters. It is felt that the average reader is easily discouraged by code letters, especially where many parts are labelled.
The author is fairly familiar with the field of food packaging in general, having spent the last five years doing packaging research and some teaching. For the past few years he has held the position of Research Assistant in Packaging in the Department of Food Technology in the Massachusetts Institute of Technology. During most of this time he has served as a member of the Technical Association of the Pulp and Paper Industry (T.A.P.P.I) Packaging Materials Testing Committee, the Packaging Institute Flexible Films and Foils Committee, and the Society of the Plastics Industry (S.P.I.) Group V, concerned with coated films, fabrics, and sheets. Each of these three committees is interested directly in developing test methods for measuring insect penetration of packaging materials. The T.A.P.P.I. test method is included in the Appendix.
II. OLFACTION AND TASTE

In order to understand why certain insects penetrate food packages to reach food, it is necessary to know something of the mechanism of olfaction and taste. Although little has been done on actual physiological mechanisms, the literature on the morphology of insect sense organs is extensive. From a study of the anatomy of sensory organs, combined with relatively simple experiments in which these organs are prevented from functioning, it is possible to make at least a few conclusions concerning the function of these organs. In most of the work referred to here, sensory organs were either amputated or else were covered with a shellac or vaseline.

In many insects it is apparent that a sense of taste exists. This sense has been demonstrated to be localized, at least in some cases, in the feet (Abbott, 1936).

In general, most authorities agree that the chief organ concerned in olfaction is the antenna (Dethier, 1941; Wigglesworth, 1939; Abbott, 1936; 1936).

Dethier (1941) has confirmed the view held by some that Lepidopterous larval antennae are both tactile and olfactory. It is obvious that the tactile sense may play a significant role where insect infestation of packages is concerned.

McIndoo (1914) has stated that, at least in the Hymenoptera, and possibly in all insects, the antennae play
no part in receiving odor stimuli. It is his opinion that the true olfactory apparatus lies in the olfactory pores he describes. According to McIndoo, the antennae and palps cannot be olfactory because they are covered with a layer of chitin. Glaser (1927) and Abbott (1936) both disagree with this viewpoint, the latter pointing out that gases pass readily through a great variety of membranes, even when they are thick, and this is especially possible where a liquid such as blood is present on one side of the membrane. It should be remembered here that the blood supply in insects is in an open or sinus system rather than in a closed system in vessels. This author has had sufficient experience with the study of permeability measurements through solid membranes to be in a position to support Abbott's opinion that gases may very readily pass through a solid such as chitin.

Mention was made above of the palps. Apparently these structures, which are really modified locomotor appendages, have both olfactory and gustatory functions, although both functions may not necessarily be found together in the same insect. Valentine (1931) states that in Tenebrio, the mealworm, the tips of the palps have a gustatory rather than an olfactory function. Minnich (1929) has shown that frequently the palps also bear olfactory organs, as in the Lepidoptera. Wigglesworth (1939) cites Sihler (1924) as showing that the cricket, Gryllus, can locate food at close quarters by means of
olfactory organs on the palps. Glaser (1927) has made similar observations on the cockroach, *Periplaneta*. Wigglesworth (1939) states that Warnke (1934) has shown that in the dung beetle *Geotrupes*, the sense of olfaction has been found to be a function of the maxillary and labial palps as well as the antennae. However, he has shown that the antennae are by far the more important in locating dung at a distance. The labial palps are not concerned in olfaction in the beetle *Dytiscus*, according to Schaller (1926) who is cited by Wigglesworth (1939). Here the olfactory senses seem to be controlled largely by the antennae and maxillary palps. Schaller showed that these beetles, when trained to associate a given scent with the presence of food could still respond so long as one maxillary palp remained intact.

It is interesting to note the effect of specialization on the distribution of the sensory function. For example, it has been shown that in the aquatic beetle *Hydrophilus* the antennae are specialized for respiratory purposes. In this case, according to Ritter (1936) as cited by Wigglesworth (1939), the sense of smell is confined to the palps.

According to Wigglesworth (1939), Hartwell (1924) has stated that in termites the antennae alone are the organs for distinguishing true odors. Apparently in termites the maxillary and labial palps have other functions. Possibly the maxillary palps, at least, are primarily con-
cerned with boring. According to Wigglesworth (1939), Glaser (1927) claims that the antennae, at least in cockroaches, have sensilla in the form of pits, cones, and plate organs. He describes sensilla as being present on the maxillary palps, labial palps, and cerci. An interesting observation made by Glaser is to the effect that more sensilla are found on insects relying on smell to locate foods and other odors.

Because of the obvious importance of a proper understanding of sensory structures, it is perhaps in order to present a brief outline of sensory structures in general. Probably the best description is found in the work of Abbott (1936). According to this authority, except for the eyes, chordotonal organs (scolopodia), and certain specialized receptors, a similar plan of organization can be found in the sensory structures of insects. These structures are all hair-like, hollow body wall extensions. They communicate with one or more sense cells. These sensory structures are classified according to the form of the "hairs". Abbott lists the following types of organs:

(Note -- Because of the brief nature of the descriptions and the probable confusion resulting from paraphrasing, it was thought advisable to quote directly.)
1- Sensilla trichodea (Hair organs) - Typical hairs, each containing or connected with a sense cell.

2- Sensilla chaetica (Spine organs) - Similar to the above, but shorter and thicker.

3- Sensilla squamiforma (Sense scales) - Surface scales connected with sense cells.

4- Sensilla basiconica (Peg organs) - These are simply shorter and wider than Sensilla chaetica.

5- Sensilla coeloconica (Sunken pegs) - As the name implies, these are sense pegs sunk in pits, much as the end of a finger on a rubber glove may be pulled into itself.

6- Campaniform organs (Sense domes) - Sense domes are simply modified hairs that are so short that they resemble rounded domes or knobs. Like other sense organs, each communicates with an underlying sense cell.

7- Sensilla placodea (Pore plates) - The pore plates occur in the antennae and palpi of various insects. Externally each consists of a thin circular or oval plate; internally this is usually grooved at the margin, the groove communicating with the fused ends of a large group of sense cells.

Abbott, C. E.
1936. The physiology of insect senses. Entomologica Americana, 16: 4 225-280

Abbott prefers to talk about the olfactory "senses" rather than sense of insects, because to him it is obvious that the sense of smell of insects is a composite one and various organs apparently perceive various kinds of chemical emanations.
III. FOOD PROCUREMENT

In order properly to understand the problem of insect infestation of stored-food products, it is essential to know something about the insects' drive to seek food, the manner in which they are attracted to foods, the types of foods they seek, and the manner in which they go about attacking the foods in order to utilize them in their metabolism. The second of these points has already been covered in the discussion of the olfactory and gustatory senses. To understand how the foods or even packaging materials are attacked, it is necessary to know something about the structure of the organs that do the attacking. These are largely the mouthparts, although the ovipositor may be used in penetrating packaging materials. As a result of holes, caused by oviposition, access to food supplies within a package is made much easier for other insects.

Brues (1946) lists three primary instincts common to all animals. These are the instinct to secure food, the self-protective instinct, and the reproductive instinct. It is the first of these instincts that is of interest here, although, as shown above, the reproductive instinct -- or more specifically, the oviposition instinct -- is sometimes of direct interest in packaging problems.
According to Ross (1948), each insect is responsive only to the particular food odors that immediately concern the species. This selective responsiveness is necessary to prevent the insect from being completely confused by a conglomeration of odors, most of which are not derived from substances that the insect can use for food. This same author points out that most insects follow odor-laden air currents and orient their approach either by an increase in odor intensity or by direction of air currents.

Brues (1946) has described feeding in insects as a purely active and never a passive process and states that for this reason feeding has modified structure and behavior considerably more than the needs for protection have. The food requirements in insects are proportionately much greater during the preparatory stages than they are during the adult stages. Large fat reserves are produced and stored in the larval stages for later use. Functional mouthparts are actually lacking in certain adult flies, moths, and other insects, according to Brues. Naturally these adults do not live long, for they are not able to feed.

Brues has outlined the types of food habits found in insects, in a convenient form, as follows:
A-Polyphagous Insects
   - insects that are quite indiscriminate in their food choice. According to Brues, these are relatively rare and usually belong to the more generalized orders.

B-Other or non-polyphagous Insects
   1-Phytophagous Insects (Vegetarian)
      - feed on living plants; about 1/2 of all living species
   1-a-Mycetophagous insects
      - feed on fungi, yeasts, etc.
   2-Carnivorous insects
      - feed on living animals
   3-Saprophagous insects
      - feed on dead or decaying animal or plant matter
   4-Parasitic insects

The groups that are underlined above are the groups that are treated in this presentation. They are the insects that are attackers of stored foods and stored-food products. Of these, the polyphagous insects are the most important economically. Undoubtedly Brues means to include the suborder Polyphaga of the order Coleoptera in his "polyphagous" insects. This suborder is an extremely large one in a very large order, and certainly Polyphaga are anything but rare. The use of the term Polyphaga for the order is a misleading one, because it implies that its members are polyphagous, which is far from being true. For example, the carrion or burying beetles, the Silphidae, are in this order, and they are definitely saprophagous, and certainly not polyphagous. Actually the distinguishing feature of the suborder Polyphaga is a structural difference rather than a dietary difference. Probably the
ants or Formicidae constitute as general a group of feeders as any. It is hard to see how ants can be called rare, however. What Brues probably means is that the number of families that are made up exclusively of general feeders are few.

The diet of insects is extremely varied when one considers that they have been found eating such items as lumber, meats, spices, corks, cigarettes, furs, paper, grains, and the bodies of other dead insects.

Frequently insects have been known to "eat" substances that are entirely devoid of nutritional content. In these cases the substances are "eaten" only incidentally. Brues lists three families of Coleoptera attacking lead pipes or lead-covered electric cables. Carpenter bees attack the same items. This same author mentions termites as consuming the rubber insulation of electrical wiring. This subject will be discussed in considerably greater detail below.

According to Brues, the sense of olfaction in insects is not as highly developed in the larvae of insects as in the adult. This is indicated by the shorter antennae in the larvae. But in spite of this, Brues points out, the larvae are highly discriminatory. In addition to olfactory stimuli, larvae react to texture, pilosity (hairiness), and other characteristics recognizable as stimuli by their
tactile organs. These tactile organs are located on the mouthparts along with the larval taste organs.

Metcalf and Flint (1939) list the several methods that food-infesting insects use to attack foods. They are as follows:

1--Deposit eggs in the developing seeds while still in the field. Only after the immature insects have been carried into the storehouse does the injury become apparent.

   Examples -- bean and pea weevils and Angoumois grain moth.

2--Enter by stealth into kitchens, granaries, or factories and deposit their eggs on cured meats, harvested seeds, or any of the products made from raw food materials.

   a--Some of the grain insects inhabit single whole grains during their entire growth period.

   b--Others attack only broken or ground seeds. They roam about in flour, meal, and other foods and contaminate much more than they eat with their excreta or the silk they spin.

3--Enter foods only on foraging expeditions. These insects have nests outside and do not breed in the stored foods. The ants are good examples of foragers. Cockroaches lead a gypsy life and are objectionable more for the filth they carry than anything else.

Metcalf, C. L., and W. P. Flint
1939. Destructive and Useful Insects.--Their Habits and Control. 2d ed.

Brues (1946) points out the pronounced correlation of form and anatomical structure with food habits. He aptly describes insect mouthparts as follows:
Mandibulate Mouthparts

-for biting and chewing foods
-the mandibles serve as cutting and chewing organs, hinged to the head at the sides of the mouth, and are actuated by muscles that serve to oppose or separate their tips.

(Note--This is the group around which this thesis is largely based.)

Haustellate Mouthparts

-for sucking blood, sap, and other liquid nourishment.

-mandibles, and also first pair of maxillae, labrum, and hypopharynx are modified into piercing or stiletto-like blades, incorporated into a beak for sucking.

-There is a 2° simplification in the higher Diptera where there is a degeneration of the blades, leaving only a lapping organ, as in the housefly.

-In a 3° simplification, the lapping organ has become elongated and needle-like, as in the Stable-fly, Stomoxys. This structure is capable of puncturing the skin of an animal and sucking blood.

Brues, C. T.
1946. Insect Dietary -- An Account of the Food Habits of Insects.

According to Snodgrass (1943), most biting-and-chewing insects are also sucking insects. He gives as examples the case of the wasps, bees, and the cockroaches. The former have jaws for biting and a pump for sucking. The latter, typical biting-and-chewing insects, are also sucking insects. The cockroaches suck with the same mechanism as the piercing-and-sucking insects.
This same authority is of the opinion that the possession of jaws for biting and chewing the food is a primitive character and that the other types of feeding organs evolved from the feeding organs of the less specialized biting-and-chewing insects.

Snodgrass (1931) describes the structural relationships between the insect head and mouthparts. According to him, the mouthparts may be defined as the external feeding organs of insects and include the following:

- **labrum**
- **hypopharynx**
- three pairs of gnathopods
  - 1st pair - mandibles -- biting and jawlike
  - 2nd pair - 1st maxillae -- the "maxillae" -- leglike
  - 3rd pair - 2nd maxillae -- always united with each other in insects to form the single labium

Usually, according to Snodgrass, the relative size of an insect's head is an index of the strength of the jaws or some other quality connected with feeding. The parietal areas of the cranium are often enlarged to accommodate the jaw muscles in the biting and chewing insects.

Snodgrass describes two basic head types. In the hypognathous type of head, the frontal aspect is directed forward and the mouth appendages hang downward from the subgenal margin. (See Fig. 63). This type is found in the more generalized insects and is, therefore, the type to be most commonly encountered in most Coleoptera, the
largest group attacking stored-food products.

In the **prognathous** type of head, the frontal aspect is turned upward and the mouth appendages are directed forward. The basal region of the labium becomes much elongated between the ventral extension of the post-occipital suture and the posterior or hypostomal parts of the subgenal sutures. It appears to be a plate of the ventral wall of the head. Blister beetles (Meloidea) have this type of head, which is more specialized than the **hypognathous**.

Perhaps some mention should be made of the specialized head and mouth arrangement in the Rhyncophora or weevils. Ting (1936) has described the condition well. The mouth-parts in this group of the Coleoptera are crowded together and modified in various ways. No labrum is present in the old family Calendridae (now in the Curculionidae), the important group that includes the granary and rice weevils. The mandibles in the Rhynchophora are proportionately thinner dorso-ventrally. At least in the Calendridae they have lost all traces of the mola. The maxillae have many of their parts fused. Because of this fusion, it is difficult to locate the exact regions of the galea, lacinia, stipes, or palpiges in many instances. The pharyngeal process located at the base of the mandible in the mesal angle is here characteristically enlarged and elongated.
In the Rhynchophora the labium has the mentum fused with the submentum so that there are but two distinct regions present, the postmentum and the prementum. As in most other Coleoptera, the labial palps are usually 3-segmented.

Typically the maxillae of Rhynchophora move in a vertical plane. This movement is made between the postgenal arm and the labium. On the other hand, the mandibles move in a more nearly horizontal plane. The cutting or gouging action of these mandibles is slightly upward. Apparently the Rhynchophora have a characteristic dorsal articulation of the mandible. The mandibles are two-notched in the mesal region so that three tooth-like points are formed.

Some mention should be made at this point of the pharyngeal process, the peculiar process attached to the inner basal angle of the mandibles. This process belongs to the stomodeal or pharyngeal wall and is, therefore, endodermal. In the Calendridae it is extremely long and extends down the pharynx the full length of the beak to the entrance of the esophagus.

Snodgrass (1931) presents an interesting discussion of the evolutionary development of the mouthparts. It seems that when the gnathal appendages gave up their primitive locomotory function and moved up to the head to function as organs accessory to ingestion, the mandibles,
being closest to the mouth, were undoubtedly the first to undergo structural modifications in adaptation to their new duties. It is probable that initially they served as mere prehensile or grasping appendages for obtaining the food and for passing it into the mouth. In the Insecta (and also the Crustacea) these appendages eventually developed into strong biting and chewing jaws. In doing so, they lost all semblance to their former leg-like structure in the Insecta. On the other hand, the first maxillae did not so completely lose their primitive form until, in some of the piercing and sucking insects, they became highly specialized as parts of an apparatus for feeding on liquid diets. In insects, the second maxillae were early fused with each other to form the median, posterior appendicular organ of the head known as the labium. This structure has more recently undergone many special modifications in its structure. The labrum and the hypopharynx were the least affected in the evolution of the mouthparts. Only in insects with piercing mouthparts are there any important changes in these structures.
IV. INSECTS AND THEIR RELATIONSHIP TO PACKAGES CONTAINING FOOD

In any consideration of the present-day stored-food product insects that have been causing so much trouble in recent times, biologically speaking, the question arises -- What did these insects do before man started to store materials for his own use? Brues (1946) quotes Linsley (1944) as offering one possible solution. It is known that many household pests infesting stored-food products also occur in the nests of wild bees, where they consume the bee bread stored for the use of their brood. Possibly many of our package-infesting insects made the simple transition to stored human food-products from this beginning.

Michelbacher (1947) suggests a few other possibilities. He says that many of them were probably living in the nests and bedding places of animals and birds. Others probably lived about the nests of other insects. Accumulations of materials that collected under the bark of trees and similar protected places probably served as food sources for still others. The food for all these insects probably consisted of material stored in nests, dead animals, cast skins of insects, hair, feathers, and other plant and animal waste.

Another group apparently fed on dried seeds, and when man started to store them for his own use, these insects found the new environment very much to their liking, and
consequently they thrived. Some of these stored-grain insects were recognized by man several thousand years ago, as evidenced by the writings of Plautus (196 B.C.), in which the Curculio is described as being a parasite in wheat. The Curculionidae are today recognized as one of the most economically important families of beetles. Up until recently the infamous Calendridae were included in this group.

_Tribolium confusum_ Jacq. Du Val, the confused flour beetle, or another insect that closely resembles it, _T. castaneum_ (Herbst), has been found in a jar containing grain in a Pharaonic tomb of about 2,500 B.C. in the 6th Dynasty, according to Cotton (1941). Both these insects are serious pests of stored flours today. Cotton tells an interesting story about a small, blind Colydiid beetle known as _Thaumaphrastus karanisensis_ Blaisdell. This beetle was not known until it was described from specimens found in supplies of grain taken from an Egyptian tomb. In 1938 it was found breeding in rice in a rice mill in Southern Texas.

It was not very long ago that man stored his seeds, herbs, roots, and dried meats for food in readily accessible locations from the point of view of the insects that attacked them. As Cotton (1941) points out, ideal conditions for breeding provided by these stores made it unnecessary for these insects to fly long distances in their
search for suitable food. Possibly as the result of the lack of need for flying about in search of food, some insects infesting stored grains have lost their ability to fly. The granary weevil, *Sitophilus granarius* (L.), has only vestigial wings remaining and does not fly. On the other hand, the closely related rice weevil, *S. oryzae* (L.), is reported to be a powerful flier. (Note -- This author has, however, never seen a rice weevil fly, although he has made numerous observations, under warehouse conditions.)

Perhaps a few words should be written concerning the typical optimum environmental conditions of stored-food product insects. Michelbacher (1947) points out that most of the stored-food product insects developed in the warmer regions of the world, and for this reason they usually have no hibernation period. Temperature regulates their activity entirely. As would be expected of tropical insects, most of them are not adapted to withstand low temperatures and are killed after prolonged exposure to temperatures of 30-40° F. Sub-zero temperatures cause almost immediate death. According to Michelbacher, the optimum temperatures for the activity of these insects lies between 70° and 95° F. Temperatures over 95° F. are harmful and even one-hour exposure at 120° F. will cause death.
Resistance to low temperatures of various insects that attack stored grain

<table>
<thead>
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<th>Insect</th>
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<tr>
<td></td>
<td>0-5°</td>
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<tr>
<td>Rice weevil (Sitophilus oryzae)</td>
<td>1</td>
</tr>
<tr>
<td>Granary weevil (S. granarius)</td>
<td>1</td>
</tr>
<tr>
<td>Sawtoothed grain beetle (Oryzaephilus surinamensis)</td>
<td>1</td>
</tr>
<tr>
<td>Confused flour beetle (Tribolium confusum)</td>
<td>1</td>
</tr>
<tr>
<td>Rust-Red flour beetle (T. castaneum)</td>
<td>1</td>
</tr>
<tr>
<td>Indian meal moth (Plodia interpunctella)</td>
<td>1</td>
</tr>
<tr>
<td>Mediterranean flour moth (Ephestia kuehniella)</td>
<td>1</td>
</tr>
</tbody>
</table>

From Cotton, R. T. Insect Pests of Stored Grain and Grain Products, 1941.

Table 2
Some species of stored-food product insects have been known to complete a life cycle in from four to six weeks and may even pass through six to ten generations a year. This statement is again from Michelbacher (1947). Because of this rapid multiplication rate, stored-food product insects have been able to inflict tremendous damage on the stores set aside by humans. In general, the optimum moisture content of the foods in which stored-food product insects live is low, occasionally being as low as 5%. Usually moisture contents of 10 to 17% are most favorable, however. At moisture contents of 17% or higher, molds and other types of deterioration set in. Under these conditions, these insects do not thrive. Brockington, Dorin, and Howerton (1949) regard moisture contents of about 17.2% (on a dry basis) and equilibrium relative humidities of 75% as being critical for whole kernel corn. Above this critical point, mold growth occurs. Obviously Michelbacher's statement of the upper permissible moisture content of stored grains agrees with this work.

As this thesis is primarily concerned with insects attacking packages, some mention must be made of the mechanism by which insects enter sealed packages. Insects found in packages may be grouped into two types, primary and secondary invaders. The primary invaders actually attack the packaging material in some form, whether it be the package wall itself or the adhesive. An opening
is made in the wall or, in the case of adhesive attack, the insect works its way under glued flaps or other sealed areas and succeeds in entering the package by an easier but more circuitous route. Once even a single opening is forced in a package by a primary invader, it is a relatively simple matter for the secondary invaders to enter. In cases where the hole left by the primary invader is too small for a secondary invader to crawl through, the latter may work on the hole to enlarge it. Once a break of any kind is made entirely through a package wall, it is easier for insects with less effective biting mouthparts to enter.

Some insects, such as the booklice and termites, are more interested in the packaging materials than in the possibility of food inside. No matter what their motive may be, they can do just as much damage as the other types. The problem of termite attack, for example, becomes serious in wartime when food supplies are shipped to tropical areas in cartons.

Frequently openings are already present in so-called sealed containers, through which many insects can enter. In the case of fibreboard packages, they may enter through small openings at the point of closure. In the case of cloth bags, they may enter through needle holes where the bags have been sewn. In many cases the adults or perhaps only the larvae can enter through the meshes of coarsely woven burlap or other bags. Even where no direct penetra-
tion by the entire adult or larva is made, it is frequently possible for the adult female to oviposit directly through the fabric and deposit the eggs in the food material within the package (Cotton, Frankenfeld, and Strickland, 1948).

Unfortunately a good proportion of the insects found in food packages even today are neither primary nor secondary invaders and did not arise from eggs oviposited through the package wall. These are the insects that went into the package with the food when it was being packaged. Or, in perhaps rarer cases, they may have been present in the fabricated container before it was filled. In either case, the effect is the same. The insects are already there and may be multiplying rapidly, especially where the shelf life of the package is long. When this type of invasion is permitted, the package is perfectly useless from the point of view of insect protection. This is true, no matter how well the package is constructed and no matter how impervious is its base material.

Where the filled container is vacuumized or where it is filled with an inert gas such as carbon dioxide or nitrogen, it is possible that all the living matter within the package will be killed. The only advantage here of this type of treatment is that further breeding is prevented. The bodies of the insects are still present, however, and the consumer is only slightly less shocked at finding dead
insects in her food packages than she would be to find them alive and crawling. Dr. Laurence V. Burton, Executive Director of the Packaging Institute, recently (1949) delivered a talk on this subject to a number of representatives of the packaging industry.

Plastic bags or liners are now being used in conjunction with multi-wall bags. These bags are usually made of polyethylene. Bags or liners of this type will afford little protection unless the plastic material is continuous. This means that the seal must be a good one.

Up to now it has been considered good practice to use the so-called "tight-wrap" construction for packages of flour and similar items. (See Fig. 50.) This type of package was first developed for the cereal industry. According to the Modern Packaging Encyclopedia (1950), the filling and sealing of the plain unprinted carton is done in the conventional way. After being filled and sealed, the carton is fed into the tight-wrapping machine. This machine automatically feeds the paper label, covers the blank side of the label with adhesive, and wraps the label tightly around the filled carton. The result is a very tightly sealed, non-sifting package. Because of the tightness of the seal, insects find difficulty in gaining access to the contents. Where a foil laminate is used, protection is naturally better than with paper alone.
Even with plastic barriers such as polyethylene, saran, etc., there is no assurance that the package will not be entered by insects with biting mouthparts. Many of the primary invaders are extremely efficient at penetrating. Insects with wood boring habits cause much trouble in this manner. According to Cotton (1945), the cadelle is one of the most troublesome of these boring insects. The larva bores into woodwork to make a sheltered place in which to hibernate or to transform to the pupal or adult form. It has jaws powerful enough to cut through "any type of package". According to Cotton, these larvae are capable of cutting through a multi-wall paper bag or a metal foil-wrapped carton overnight. Cotton lists larvae of termites and of hide beetles (*Dermestes vulpinus* Fab.) as other severe troublemakers. Hide beetles have been seen leaving their natural habitats, animal hides, or other desirable commodities, in order to burrow into packaged products of all kinds nearby.

Numerous references have been made in the literature to insects, primarily Coleoptera, that are capable of boring their way through lead. This ability illustrates the tremendous penetrating power of the insect mouthparts. It is obvious that almost any flexible packaging material can be penetrated by some kind of insect.

The best insurance against delivering insects along with the product to the consumer is effective plant sanita-
This all-important subject is beyond the scope of this thesis and, therefore, will not be treated here. On the other hand, there are many food packagers who have done a creditable job of keeping insects out of their packages up to the point of filling and sealing. These people are interested in further checking, to make sure that they have used the best possible packaging material consistent with cost that will continue to keep insects out of the package. In some cases these packers have used repellents, either applied to the packaging material itself or to the adhesive. Repellents are usually volatile, and for this reason their effective lives are limited. Furthermore, they add additional cost to the package, and in cases where the margin of profit is already small and the customer is accustomed to paying a certain fixed price for the item, the extra cost may be prohibitive. One of the objections to the use of repellents lies in the possible toxicity to man if any of it contacts the food. Even if the material is known to be non-toxic, it is quite possible that the odor will be objectionable to the consumer. Some work has been done by Frings (1948) on the use of inorganic salts as repellents. The paperboard used in Frings's experiments was impregnated with the appropriate salt solution, dried, and then coated with paraffin or other wax. Ammonium and potassium nitrates and chlorides were found to be promising. They have the advantage of being easily obtained. In addition, they are non-toxic to man, non-volatile, and non-odorous.
Usually it is relatively easy to detect whether or not a package has been infested with insects. The adult stage is frequently present, and as the adults of stored-food insects are usually black and motile, they are readily seen, if they are present in any number. It is less easy to detect larvae, for these are more nearly the color of most food products. The early larvae, being extremely small, are especially difficult to notice. It is almost impossible to detect eggs with the naked eye. According to Wagner and Cotton (1937), 10XX cloth will remove all eggs of flour infesting insects, so they can be checked for in this way.

Another common way to detect insect infestation or contamination in flour is a method devised by Howard of the Food and Drug Administration (1939). Here the detection of the presence of insect excrement is based on the different reaction of flour particles and pellets of excrement, when moistened with oil. In this test, the flour particles become clear and transparent. On the other hand, the pieces of excrement remain white and opaque.

Harris and Helsel (1938) have developed a flotation test for determining the presence and the quantity of insect fragments and other filth in flour.

Wagner, Cotton, and Jones (1938) have shown photographs (Fig. 49) of the excreta of the common stored-food product insects. These may be of some help in checking for
a history of contamination where no living or dead insects or fragments can be found.

An interesting method has been described for detecting weevil infestation in grains (U.S.D.A., 1948). Grain samples are soaked for a few minutes in a dye containing acid fuchsin and then washed. Small cherry-red dots appear where weevils have laid eggs in the kernels. Female weevils lay their eggs in small punctures that they gnaw on the surface of the kernel and then carefully plug the hole with a jelly-like material. After hardening, the plug seals the hole and the kernel looks perfect from the outside. The plug of hardened jelly-like material takes up the color of the stain.

The problem of measuring the insect resistance of packaging materials is one that interests many people. Tests of this kind are or should be carried out by government agencies, suppliers, converters, and packagers. At present several types of test are being used, and not one has become universally enough adopted to warrant being called the most satisfactory standard test.

In general, these tests utilize insects that are known to be effective primary invaders. Most often larval stages are used, because of their greater penetrating power. Where possible, optimum temperature and humidity conditions are provided. Unless the insects are kept at reasonably high humidities, they are apt to die of desiccation.
tion before they have a chance to show their penetrating powers. On the other hand, they also require a certain amount of food to remain alive and active. It is difficult to determine whether a better test is provided when moisture and food are wanting and the insect has to penetrate the barrier to get at these life needs, or when small amounts of food and moisture are available to the insect all during the test. Completely false conclusions can be drawn regarding the penetrating effectiveness of insects that are not stored under suitable conditions throughout the tests. For example, a certain insect may be able to effect entrance through a packaging material in four days under ordinary conditions. However, if the insect cannot possibly live more than three days under the test conditions, because of starvation and desiccation, it will obviously not succeed in puncturing the packaging material. Careful watch should be kept over the insects to determine when they die.

Another factor to be considered is the need for insects to gain a foothold so that they can most effectively use their biting and chewing mouthparts. Misleading results may be obtained in this manner also, for it is rare for an insect to be exposed to a completely smooth and bare surface. Even particles of food will help provide this necessary anchorage.
One of the strongest urges in insects is the desire to oviposit. This is usually done in protected spots, sometimes in cracks and crevices, as well as folds of paper and board. Sometimes it is done directly in a food material. At any rate, the urge to oviposit must be taken into consideration when insect resistance tests are arranged.

It is obvious from the above points that there is a distinct advantage in providing at least a small amount of food on the insect side of the barrier. This food will provide nutritive elements, a certain amount of moisture, something of a foothold, and a place to oviposit.

One of the proposed test methods is that of the Technical Association of the Pulp and Paper Industry (T.A.P.P.I). This method is referred to as T 473 m - 47 Insect Resistance of Packages, Paper, and Paperboard. (See Appendix.)
Another method was described by Essig, Hoskins, Michelbacher, and Smith (1944) at the University of California. These workers used about fifteen species of insects in their studies but reported in detail on the method used for the cadelle larvae, *Tenebroides mauritanicus* (L.). Small packages (3 x 5.5") were made up and placed in gallon glass jars. Ash cans were usually used for larger packages. The bottoms of the containers were covered with a disk of Kraft paper to provide better footing for the insects. In some cases contamination was simulated by sprinkling 10 to 50 grams of whole wheat flour on the bottom paper disk. This flour was not placed directly on the package, because it might have affected the penetration of the package by the insects. Ordinarily 25 cadelle larvae were used in each gallon jar. Storage conditions were at 80° F. and 50% relative humidity. At the end of two weeks, the packages under test were given a preliminary examination. If any signs of penetration were found, the packages were opened and examined from the inside. Multiwall containers must necessarily be examined with extra care, layer by layer. The authors were able to examine the material for small holes with the aid of a bright lamp.

Chemical repellents were tested by impregnating toweling paper with them, after which the toweling was wax coated. These coated papers were formed into packages with the aid of heat seals and then filled loosely with
flour. In this test, two bags treated with the same repellent were placed at the bottom of a large battery jar with a small amount of flour and ten large cadelle larvae. Storage conditions were at 30° C. and 60% relative humidity.

Essig and his associates also did some work with sheet materials as opposed to packages. The sheet material was placed over the mouth of a Mason jar and sealed into place with a Kerr-type lid. In some cases, the sheet material was deliberately creased. The test larvae were placed in the "arena". As they penetrated the sheet, they dropped through the opening and into the jar.

Derby (Proctor and Sluder, 1942-1943, 1943-1944) used a crystallizing dish technique for most of his studies. The crystallizing dishes were used in pairs, with the open sides facing each other. The material to be tested was placed between the dishes, and the larvae or adults were placed in the top dish. A food incentive was placed in the lower dish. In a variation of the technique with cadelles, grain was placed in the upper chamber with the beetles. In testing some of the packaging materials, Derby inverted a single crystallizing dish containing several larder beetles and a small piece of dried beefsteak over a surface of the package. It was possible to concentrate the beetles over a small area by the use of this technique.
In testing medium-sized packages, Derby constructed glass cages from glass panes. These panes were cemented together with Tilette, a plastic cement. The top of the cage was covered with cellu-glass, an insect-proof material, to prevent the insects from escaping. A small amount of dried beef was placed in the cage with the beetles and the package under test.

In carrying out tests on the insect-resistance of packaging materials, one must decide what insects to use. Naturally, insects are chosen that are known to be effective package penetrators. If packaging materials will stand up under attack by the efficient borers, they will certainly withstand attack by the less effective borers. As pointed out above, there are several different methods of testing. In addition, a number of test organisms are used, with some degree of disagreement in the literature as to the relative efficiency of each insect. Perhaps it will be useful to say something about these test insects.

The cadelle larva is generally conceded to be one of the best penetrators (Essig et al., 1944). On the other hand, Derby (Proctor and Sluder, 1942-43, 1943-44) found the larder beetle larva (Dermestes lardarius L.) even more efficient than the cadelle larva. Termites were found by Derby to be very effective also. The lesser grain borer adults, *Rhizopertha dominica* Fab., also have proved to be rather effective, according to Essig and his co-
workers. They also list the granary weevil adult (*Sitophilus granarius* L.) as being fairly efficient.

The flour beetles have varying effects. Probably the most efficient is the broad-horned flour beetle (adults and larvae), *Gnathocerus cornutus* (Fab.). The lesser grain borer adult is just about as efficient as these insects. The adults of the drugstore beetle (*Stegobium panicum* L.) have been found by Essig and his coworkers to penetrate several packaging materials. The false black flour beetle adults and larvae (*Alphanotus destructor* Uyttenberg) have some penetrating power. This same group worked with the adults and larvae of the confused flour beetle (*Tribolium confusum* Jacq. Duval) and the adults of the saw-toothed grain beetle (*Oryzaephilus surinamensis* L.). In neither case did they succeed in getting penetration. On the other hand, Back and Cotton (1926) obtained penetration by the latter species. Essig et al. obtained no penetrations of any great significance with the moth larvae tested, *Plodia interpunctella* (Hübner), the Indian meal moth, and *Ephestia* spp., to which latter group the Mediterranean flour moth belongs.

With regard to the termites used, Derby (Proctor-Sluder) makes no mention of species, but he does say he used adults. Chamberlain and Hoskins (1949) reported considerable work on termites and other insects with a modification of the Mason jar technique of Essig et al. For their final tests they used the common dampwood termite, *Zootermopsis*
angusticollis, and the Nevada dampwood termite, Zootermopsis nevadensis. These workers found the termites penetrating toweling paper, 300 gage cellophane, and kraft paper even more rapidly than the cadelle larvae. In general, they also found that the larva of the mealworm Tenebrio molitor was for some materials slightly more efficient than the granary weevil adults.

Experiments were also carried out by Chamberlain and Hoskins (1949) on the drywood termite, Kalotermes minor. The drywood termites make small round holes perpendicular to the surface of the packaging material, whereas the dampwood termites scrape out large areas and expose much of the glue. These behaviors are what would be expected from the insects' normal boring habits. They are responsible for the decided superiority of the drywood termite in penetrating cardboard. Dampwood termites are more susceptible to DDT than the drywood species because of the smaller amount of wax on the former. The dampwood species is also more likely to enter food packages than drywood termites, for food packages are often left on damp floors or beaches where the insects are frequently found.

Verdcourt (1947) has done some preliminary work showing the penetrating power of certain insects with plastic materials. According to him, adults of the drugstore beetle, Stegobium panicum L., can penetrate cellulose-based plastics as well as board, paper, and cork. These
cellulose-based plastics, which include cellophane and ethyl cellulose, are penetrated at low temperatures as well as at ordinary temperatures. On the other hand, he showed that polyvinyl chloride, polyvinyl chloride-acetate copolymer (Vinylite), polyvinylidene chloride (saran) and, to a lesser degree, rubber hydrochloride (Pliofilm) are much more resistant even at the optimum temperature for insect activity. The samples of polyvinylidene chloride used by Verdcourt were of the oiled variety and appeared to have a slight insecticidal action. The names included in parentheses are those of the usual commercial plastics found in this country. They are mentioned because in the United States they are in more common use than the chemical names.
V. DESCRIPTIONS AND DISCUSSIONS
OF THE MORE IMPORTANT STORED-FOOD PRODUCT INSECTS

A. Order ACARINA (of Class Arachnida)

Tyroglyphus farinae De Geer

Flour Mite
Common Forage Mite
Grain Mite

The flour or grain mites are grayish-white, pale, soft-bodied, smooth animals of microscopic size. They possess numerous long hairs on the legs and back. They are not true insects but belong to the class Arachnida, which includes the spiders. No wings are present. The body has eight legs and is indistinctly divided into two parts. Usually they are less than 1/50 inch long. These creatures multiply with great rapidity. The entire life cycle may require only a little over two weeks. Often they are found in stored grain, where they may breed so fast that the grain gives the impression of being alive.

In large numbers they promote sweating, impart a disagreeable odor to the grain, and may cause damage by their feeding. Fortunately these flour mites are themselves parasitized by other mites, which soon render them ineffective.

Mites reproduce by means of eggs laid over the food. The young mites are at first six-footed, but they develop two more legs. A hypopus, which is a resistant non-feeding stage, is often characteristic of these creatures. The mites are very active in this stage, in which the body wall
hardens and suckers are formed on the ventral side. By these suckers, the mites attach themselves to other insects or to mites for transport to new locations. In this stage, mites may last several months without food. Because of this fact, it is difficult to clean up mite-infested premises.

Mites have been found attacking the following: grains and all kinds of grain products, other seeds, especially oil seeds, dried fruits, cheese, jams, preserved meats, tobacco, hair, fur, feathers, yeast, drugs, spices, copra, and stored products.

Mites require a high moisture content (at least 13%) in the foods they are attacking. This high figure indicates that mites may be associated with the presence of molds on the substances attacked. However, as Blake (1943) points out, mites will attack substances that are not moldy.

E. Order THYSANURA

*Lepisma saccharina* L. Silverfish
*Fishmoth*
*Slicker*

This is a silvery gray species, about 1/2 inch long, except for the caudal filaments. This insect belongs to an extremely simple group of insects, the Thysanura. It runs with great rapidity. The body tapers markedly from head to tail and is covered with thin scales, giving it a silvery, shiny appearance. The long antennae are almost the same length as the tail appendages. The color is a
uniform silvery or greenish gray. The upper surfaces of the insect are scaly, and the scales rub off easily.

This insect prefers damp places near the soil, such as basement rooms and porches. It lives best at about 80° F. and close to 100% relative humidity.

It is cosmopolitan in distribution and feeds on all kinds of starchy foods, such as flour, oatmeal, cereals, etc. It also attacks glazed papers, protein-sized papers, books, cellophane, glue, freshly dried beef, dried plants, book bindings, and starched clothing. It apparently requires a certain amount of protein in its diet.

This species is killed easily at 98° F. and also at 32° F.

C. Order ORTHOPTERA

Blatta orientalis L. Oriental Cockroach

According to Back and Cotton (1940), this species is probably the commonest cockroach species found in flour mills and food establishments in North America. For this reason it is discussed here rather than the well-known American and German cockroaches.

This insect is about 1 inch long and uniformly darkish brown or black. The males have wings much shorter than the abdomen; the females are nearly wingless. The wings on the male are fully functional. The female is heavier and broader than the male.
About thirteen months are required for the life cycle. The female produces an average of 14 or 15 capsules, averaging 12 to 16 eggs each. These capsules are 1/2 inch or so in length. The young are nearly colorless during the first and second stages. Metamorphosis is gradual.

The jaws are not particularly strong, so their diet is restricted to reasonably soft products such as human food, and they erode the surface of cloth and paper for the sizing. Damage is done to starchy foods, cheese, wool, old leather, and beeswax.

Distribution is cosmopolitan, and the insect is frequently carried on ships. The English call this roach the Black Beetle, because it somewhat resembles a beetle in appearance.

It is killed in 10 minutes at 131° F., according to Blake (1943).

Other commonly encountered species include Blatella germanica (L.), the German cockroach, and Periplaneta americana (L.), the American cockroach. The former is most common in kitchens and bathrooms; the latter is abundant in city dumps, basements, restaurants, bakeries, packing houses, and among groceries.
D. Order ISOPTERA

Reticulotermes flavipes  Eastern Subterranean Termites

This species is listed, not because it attacks food for the sake of the food itself but because it is known to attack a great many packaging materials containing foods. It occurs, according to Blake (1943), in eastern North America. As is the case with most termites, this species bears a superficial resemblance to ants, although in the termites the abdomen is joined very broadly to the thorax, there being no constriction or "waist" present. These insects get the name Isoptera ("equal wings") from the fact that they have two pairs of almost equal membranous wings when wings are present at all. They also have a pair of short, terminal abdominal appendages or cerci. The bodies are almost without pigment, except for the swarming sexual forms, and are fairly soft. In fact, termites are so soft because of poor sclerotization that desiccation takes place easily.

There are four castes, consisting of:

1-Dark-bodied males and females with four long wings; called kings and queens
2-Short-winged males and females
3-Wingless males and females
4-Wingless workers
5-Wingless soldiers } sexually immature

No attempt will be made here to go into the rather complicated life cycle. Termites (at least all the wingless castes) seem to have an aversion to being exposed to the
open air. The mouthparts are of the chewing type, and the mandibles of the soldiers are especially large.

The food of most of our termites is wood. The insects cannot digest cellulose but harbor protozoa in their digestive tract which can. These insects live in a symbiotic relationship with the protozoa, which digest the cellulose for them. According to Blake (1943), the Eastern subterranean termite will readily attack paste-board, paper, vegetable parchment, cellophane, and cotton cloth. However, this same authority states that it consumes material rather slowly -- about 0.002 cubic millimeter of paper per termite per hour at room temperature, for example. This species also attacks electrical insulation and lead foil.

Chamberlain and Hoskins (1949) showed that Zooter-moosia nevadensis and Z. angusticollis were in several cases more efficient penetrators than the extremely efficacious cadelle larvae. The results are summarized below, in part:

<table>
<thead>
<tr>
<th>Insect</th>
<th>Toweling</th>
<th>Asphalt bagging</th>
<th>#300 Cellophane</th>
<th>50# Kraft paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z. nevadensis</td>
<td>3 hrs.</td>
<td>8 days</td>
<td>5 days</td>
<td>1 day</td>
</tr>
<tr>
<td>Z. angusticollis</td>
<td>3-1/2 hrs.</td>
<td>7 days</td>
<td>4 days</td>
<td>1 day</td>
</tr>
<tr>
<td>Cadelle larvae</td>
<td>1 day</td>
<td>4 days</td>
<td>8 days</td>
<td>5 days</td>
</tr>
<tr>
<td>Mealworm</td>
<td>19 days</td>
<td>&gt;40 days</td>
<td>40 days</td>
<td>----</td>
</tr>
<tr>
<td>Adult granary weevil</td>
<td>29 days</td>
<td>&gt;40 days</td>
<td>&gt;40 days</td>
<td>----</td>
</tr>
</tbody>
</table>
In tests with dampwood termites, the above workers used a relative humidity between 70 and 90% at 29° C. Termites do not ordinarily give much, if any, trouble with packages in food plants or in the house. However, in military operations, where cartons of food are left exposed on the ground, they are tremendously annoying, and for this reason they must be considered by packaging technologists. Also, as they are especially good penetrators, they are useful to employ for accelerated package or packaging materials penetration tests.

It is likely that some species of termites can be the found almost anywhere in this country for use as test insects. Termite can be found almost anywhere in the country for use as test insects.

E. Order CORRODENTIA (=PSOCOPTERA)

Troctes divinatoria Mull. Common Booklouse

Swain (1948) calls this insect Liposcelis divinatorius, which may be the most recently accepted name. The insect is about 1/25 inch long and is a pale-grayish or yellowish-white, wingless, soft-bodied, louse-like animal with a large head and long slender antennae. It feeds on a large variety of organic matter, including eggs of the Angoumois grain moth, molds, books, ground feed, dried vegetable materials, cocoa, flour, and cornmeal. It is troublesome more for its presence than for the actual damage it causes.
This insect is widely distributed in North America and Europe. No males are known to exist. Up to 100 eggs are laid by an adult. In summer, the developmental period from egg to the mature insect is about 3 weeks, although it may require up to 130 days in cooler weather. About 65% relative humidity is preferred. High humidities are needed to prevent desiccation of the soft bodies. The newly hatched young resemble the adults, although they are smaller and of a lighter color.

These insects have chewing mouthparts and six long legs. They are killed at 140°F.

**F. Order LEPIDOPTERA**

*Ephesia sericarium* (Scott) Mediterranean Flour Moth

Mill Moth

This moth is usually reported in the economic literature as *E. kuehniella* Zeller, although *sericarium* is technically the correct specific name. Until a short time ago this moth was the most troublesome pest of flour mills in the United States. It was first reported in Germany in 1877 and reached California in 1892. Since that time it has spread throughout the country. The primary nuisance value of this insect lies in the silken threads spun by the larvae. These web and mat the flour particles together, and the machinery becomes seriously clogged. Because of modern fumigation methods, this moth is no longer as troublesome as it used to be.
The adult has a wingspread of about 1 inch. The hind wings are a dirty white, and the fore wings are pale gray, transversed with zigzag blackish lines. The length is 1/4 to 1/2 inch. While the insect is resting, the head and abdomen are slightly raised.

The female lays eggs in accumulations of flour or other foods. Sometimes these are laid on the cloth in spouts or bolters in mills, or in cracks about buildings. The eggs hatch in from 3 to 6 days, and the emerging caterpillars immediately begin spinning silken threads and form little tubes, in which they live and feed. When full-grown, these larvae are about 3/5 to 1/2 inch long and whitish or pinkish in color, with a few small black spots on the body. Pupation takes place in silken cocoons. A reddish-brown pupa is formed, which persists for 8 to 12 days.

Development in summer requires 8 to 9 weeks. Eggs hatch only between 53° and 90° F. However, the lowest temperature for development is said to be about 46° F. Data on humidity requirements are lacking.

This moth is killed at 115° F. in 3 hours, and at 10° to 15° F. in 4 days. Old larvae and pupae can withstand 32° F. for several months, however.

Essig et al. (1943) showed this moth to be a rather poor penetrator of packaging materials, although these workers did obtain some penetrations. Blake (1943), on the other hand, reported that the larvae do not penetrate paper, although they are capable of passing through tiny openings.
The diet consists largely of grain and flour, although the following are also attacked:

- dates
- chufa
- figs
- almonds

- nuts
- raisins
- cacao
- chocolate

- army biscuits
- beans
- dried peppers
- dried bananas

- "jelly cubes"
- stored potatoes

**Plodia interpunctella** (Hübner) Indian Meal Moth

This moth is probably the most troublesome moth attacking stored food products. The larvae attack cereal grains, whole or processed, although coarsely milled to finely milled materials are preferred. They, like the Mediterranean flour moth larvae, cause trouble with webbing spun by larvae in mills, food processing plants, and warehouses, especially in the late summer.

The adult is a rather handsome moth with a wing expanse of nearly 3/4 inch. It can be distinguished from the other grain-infesting moths by the characteristic markings of the fore wings, which are reddish brown with a coppery luster on the outer two-thirds, but whitish gray on the inner end. The underwings are grayish white. When at rest, the wings are folded closely together along the line of the body, and the antennae rest on the wings. The palps form a characteristic cone-like beak in front of the head. The adults are active at night or in dark places.

The female lays from 100 to 350 eggs, singly or in groups, on food material. These hatch in from 2 days to 2 weeks into small caterpillars of a general white color, but often with a distinct greenish or pinkish tinge, with
a light brown head, prothoracic shield, and anal plate. The larvae feed on grains, grain products, nuts, and the following:

- coffee substitutes
- chocolate
- drugs
- nougats
- coffee
- tea
- corn
- soybeans
- cottonseed meal
- dates
- dried bananas
- dried nectarines

When full grown, the larvae are about 1/3 to 1/2 inch long. The larva crawls up to the surface of the food material and spins a silken cocoon, within which it pupates. The adult emerges from the light brown pupa in 4 to 30 days. Usually there are 4 to 6 generations a year, and the entire life cycle is said to require from 4 to 6 weeks.

According to Blake (1943), the mature larvae can penetrate tinfoil, aluminum foil, greased paper, and walnut shells. However, it cannot penetrate 18-mesh wire gauze, nor will it penetrate Eulan-treated fabrics.

The optimum temperature is 83° F., although development takes place between 52° and 89° F. The optimum moisture content in food is 18%. Adults die immediately at 117° F., or in 30 minutes at 113° F. They also die at 10° to 15° F. in 5 days. It is possible to disinfect dried fruit at 145° F. in 10 to 15 minutes. Packaged fruit should be heated to 125° to 130° F. for one hour after it is packaged and sealed, in order to kill any of these insects that may be present.
An interesting observation is that, although old coatings of chocolate will not protect fruit cakes, marzipan, etc., a fresh thick coating will (Blake, 1943).

Smallman (1945) has made some calculations on the numbers of progeny of a single pair of adults of this species. If each female lays about 200 eggs, the first generation will consist of 200 adults, formed in about one month from these eggs. These 200 adults are again theoretically capable of forming a second generation of 20,000. This number of progeny from a single pair would give trouble enough, but occasionally there is at least a partial third generation of 2,000,000. This partial third generation may form even in Canada. When and if it does, it produces infestations of outbreak proportions, to the surprise and concern of warehousemen and cereal plant operators. Fortunately these theoretical increases are progressively limited, as the population becomes progressively larger, by sterility of the adults and by parasitization by a tiny black wasp (Microbracon hebetor Say). Smallman was not trying to drive home any definite point with this particular species, but rather he was attempting to show how rapidly insect populations can increase under optimum conditions.

This insect was described in 1827 by Hubner but was first referred to as the Indian meal moth by Fitch, who found the larvae feeding on cornmeal. Because it feeds on nearly all dried foodstuffs in the average home and is so frequently seen flying around houses, it is often mistaken for a clothes moth.
Sitotroga cerealella (Olivier)  Angoumois Grain Moth

This moth was a serious pest in Angoumois, France as early as 1736. It causes severe damage to soft red winter wheat in the eastern and central states, and to corn in the southern states. The early settlers bringing in wheat supplies from the old country were said to have brought it into this country.

Cotton (1941) states that a Col. Landon Carter reported injury from this species as early as 1728 in North Carolina. The first scientific description of the insect was in 1789.

The adult is a rather delicate moth, buff-colored, and with a wingspread of 1/2 to 2/3 inch. Because the eggs are almost microscopic and the larvae and the pupae live entirely within the seeds, this is the only stage commonly observed. The hind wings are uniformly light gray, with a heavy fringe of hairs that are longer than the width of the wing membrane (typical of Gelechiidae). The wing membrane is prolonged at the apical angle like a thumb or finger, which easily distinguishes it from the clothes moth, with which it is often confused.

The adult females usually lay about 40 eggs, although up to 389 have been recorded. These eggs are white to reddish and are laid singly or in clusters of as many as 20, on the grains where the larvae feed. When the larvae are outdoors, the eggs are attached to wheat heads in the
These eggs hatch into minute white larvae that bore into the kernels of the grain, feeding upon the starchy parts of the kernel. When full-grown, the larvae are about 1/5 inch long, white with a yellowish head, six true legs, and four pairs of prolegs. Before pupating, the larvae cut a channel close to the surface of the grain to permit the adult to escape. A thin silken cocoon is spun within the grain. Usually the larval stage lasts about 20 to 24 days, and the entire life cycle may require only about 5 weeks. In some cases the larvae may remain dormant over the winter. There may be from 2 to 6 generations a year.

A temperature of at least 50°F is required for reproduction. Above 95°F, reproduction does not occur. This moth is rather resistant to high temperature, according to Blake (1943). It is killed in 1-1/2 hours at 140°F and in 15 to 20 minutes at 176°F. The required moisture content in grain is about 12%.
Order COLEOPTERA

Acanthoscelides obtectus (Say)  Common Bean Weevil

This species is believed to be a native of North America, but it is now completely cosmopolitan.

The adults are about 1/8 inch long, with reddish appendages. The body narrows evenly toward the small head. Small black mottlings are visible in the part of the abdomen exposed to view dorsally. The presence of one large and two small teeth at the apex of the hind femur helps to distinguish the beetle. The author has noted that a general fuzziness of the elytra is also characteristic.

Whitish, ellipsoidal eggs are laid in loose groups of a dozen or more, in holes chewed by the females in the green pods along the seam where the two parts of the pod meet, or in any natural crack they find in the pod. Three to 30 days later, minute, whitish, hairy grubs hatch from the eggs. These grubs are equipped with short, slender legs. They scatter throughout the pod and seek out the developing seeds, eating their way to the inside. Because of their very small size, the holes through which they enter heal over and leave only a slight brown dot. This makes detection difficult.

The larvae feed for several days and then molt, appearing as white grubs with very small heads, no legs, and no long hairs. Feeding and growth continue until the larvae are about 1/8 inch long, about 1/4 inch wide, wrinkled,
and humpbacked. The larval stage takes anywhere from 2 weeks to over 6 months. The pupal stage is passed in the larval cell, which has been cemented over on the inside to exclude the larval excrement from contaminating the pupa, and which has a cylindrical extension to the outside. This extension does not penetrate the seed coat. The adults usually escape through these circular holes 2 to 8 weeks after the larvae enter the seed. The adults emerging from seeds out-of-doors look for growing beans on which to deposit their eggs. When the beans are harvested, all stages are apt to be taken into storage. The adults, as they transform, continue to lay eggs among the beans.

A relative humidity between 26 and 93% is needed for reproduction. The optimum temperature is about 86° F. Reproduction occurs between 62.5° and 93° F.

This species is almost exclusively a pest of stored beans. Although it primarily infests navy and kidney beans, it also occurs in lima beans, cowpeas, common peas, field peas, Windsor peas, lentils, chick peas, and seeds of *Lathyrus sativus*. 
Carpophilus hemipterus (L.) Dried Fruit Beetle

The fig industry in California has been particularly bothered by this insect, because of its habit of carrying microorganisms with it when entering figs. These microorganisms cause smut and souring of the fruit. Unfortunately for the fig growers, this beetle is part of what might be called a "vicious circle". The beetle is attracted by fermenting fruit, upon which it picks up the infecting microorganisms with which it is able to infect other fruit, thus causing further fermentation. The dried fruit beetle also attacks:

- watermelons
- prunes
- dried fruit
- copra
- apples
- peaches
- corn
- beans
- grapefruit
- apricots
- wheat
- nuts
- bread
- oranges
- rice

The adults are active, strong fliers. They gain entrance into the figs through the "eyes". The average sized beetle is about 1/8 inch long and 1/16 inch wide. The wings are too short to conceal the last two or three abdominal segments. Each elytron has a prominent amber-brown spot at the tip and a smaller one near the base, on the side. The head is rather large, with conspicuous eyes and 11-segmented, clubbed antennae of amber or reddish color. The rest of the body is black.

The adults deposit about 1,000 small white eggs on the pulp of ripe figs while on the tree, or on a pile of cull oranges, raisins, watermelons, or other fermenting...
fruits. In about two days the eggs hatch into whitish, hairless, short-legged grubs, with brown heads and brown posteriors. These grubs reach their maximum length of 1/4 inch in a week or two. Pupation takes place for about a week in the soil.

In warm weather there may be a generation of insects every three weeks. At other times the developmental period may be several months.

Dermestes ater De Geer  

This insect is probably the same as D. caderiverinus Fab., known as the incinerator beetle. It is a cosmopolitan species and has been reported doing damage to dried fish, cheese, copra, hog bristles, dried mushrooms, silk, leather, wool, cacao, and ginger (Blake, 1943). It is commonly found infesting cockroach colonies. Roth and Willis (1948) have carried out considerable research on this species. Their data are used in this brief presentation.

The adults are a dull black and generally resemble the larder beetle, D. lardarius. The sexes in adults can be easily separated with the aid of a low power dissecting microscope. A small stout seta surrounded by golden colored hairs is present in the male along the mid-ventral line of the third and fourth sternites. Females do not have this secondary sexual characteristic. The adults are
long-lived but require food for longevity. At emergence, the females are sexually immature, and the ovaries of starved females remain undeveloped. The female begins to oviposit in about eight days, if given meat and mated with a male. The female requires repeated matings to attain full potential fecundity.

The eggs are uniformly pearly white, when laid. At 27° C., most eggs require less than three days to hatch. Under optimum humidity conditions, the larval period lasts about one month. Fluid water has been found essential to maintain larval development periods as short as this. Simply moistening the food medium causes molds and bacteria to develop. The larvae are capable of boring through cork, paper, and cardboard. The larvae are cannibalistic, especially when food is lacking. Even pupae are attacked by larvae (and also by adults).

Females of *D. atro* require the stimulus of an oviposition site before laying eggs. This site may be a crevice or a loose medium such as sand or fishmeal. Food is not required as an oviposition stimulus under these conditions. The average width of a slit preferred as an oviposition site for single eggs is slightly less than 1/2 mm.
Dermestes lardarius L.  

This beetle is now cosmopolitan in distribution, but it is especially common in Northern Europe. It feeds on feathers, horn, skins, hair, beeswax, ham, bacon, dried beef, and a wide variety of other substances including the following:

- dried crabs
- peanuts
- chocolate with puffed rice
- salt pork
- sponges
- nutmegs
- tobacco
- cheese
- grain products
- nuts
- dog biscuits
- cacao
- dried pears

According to Blake (1943), it is one of the few insects able to attack natural sponges. It can penetrate 0.2 mm. of lead in 4 hours and the same thickness of tin in 36 hours. However, it will not attack aluminum, zinc, or brass. It avoids lard and fat, in general.

Although this insect generally attacks materials of animal origin, it gives little trouble in this country, simply because few people store meats and similar products where insects can get at them. This difference is probably largely due to the advanced state of the refrigeration industry in this country. Consequently these insects are in no position to get at our "larders".

The adults are 1/3 inch long and are very dark brown, with a wide, dirty, yellowish band across the anterior portion of the wing covers. On this band are 6 black dots, 3 on each wing cover. These dots are in the form of
a triangle on each wing. The female lays the eggs either in sheltered spots near the food or directly on the food. The larvae reach full maturity in 40 to 50 days, when they attain a length of slightly over 1/3 inch. Pupation takes place right inside the larval skin.

Inasmuch as the larder beetle larva is one of the most efficient borers known, it has been widely used as a test insect. In general, the genus *Dermestes* is known for its habit of boring into soft wood for pupation. Probably for this reason the larvae are such excellent borers. The adults, like other Dermestids, frequently are found outdoors on pollen-laden flowers.

The infamous larder beetle larvae are extremely hairy and brown. They taper towards both ends of the body. Although they somewhat resemble carpet beetle larvae, they can be distinguished from the latter by the presence of two short curved hooks on the last segment.

*Dermestes maculatus* De Geer

Skin Beetle

This beetle is also known as *D. vulpinus* Fab. The hide beetle is somewhat more elongated in shape than other Dermestids. The adults are black above and whitish beneath, and generally from 1/4 to 1/3 inch long. The larvae are sometimes used by museum workers to clear the dried flesh from delicate skeletons of small animals. The hide beetle is widely distributed and is commonly seen infesting ship-
ments of raw hides. Development requires from 5 weeks to 8 months. The optimum temperature, according to Blake (1943), is above 80° F. Storage at 40° F. or below tends to protect hides, as does salting.

\textit{Gnathocerus cornutus} (Fab.) Broad-Horned Flour Beetle

This insect, when viewed under a magnifying glass or dissecting microscope, is a rather terrifying looking creature because of the impressive structure of the mandibles or jaws of the male. These jaws have the shape of a pair of broad, stout horns. The beetle is reddish-brown in color and about 1/6 inch long. The adult closely resembles the other flour beetles, except for the prominent mandibles and the rather robust appearance.

The females lay from 100 to 200 eggs, which hatch in 4 to 5 days in warm weather. The entire development period requires from 8 weeks to 7 months. According to Blake (1943), the optimum temperature is 70° F.

The broad-horned flour beetle is found in many parts of the country, but it is cosmopolitan in distribution. It prefers flour and meal, but it is also found in grain, raisins, rice, cacao, and ginger.

Essig \textit{et al.} (1943) have shown that this insect has fairly good penetrating powers. This would be expected from the nature of the mandibles. Both adults and larvae were used together in the tests of these workers.
Laemophloeus ferrugineus (Stephens)  Rust-Red Grain Beetle

The rust-red grain beetle adult is about the same size as the adult of the flat grain beetle. It, too, is reddish brown and flattened in form. The habits are similar to both the preceding species. The antennae, however, in the male beetle are only half as long as the body or less. This species is found in more northern regions than the other two species because of its greater resistance to cold weather.

It occurred to this author that the name "rust-red" is associated with two separate groups of flour and grain-infesting insects. In each of these groups there is an extremely close similarity between the "rust-red" species and another species. (See Confused flour beetle and rust-red flour beetle.) It would appear to be quite likely that the layman will confuse even the rust-red grain beetle and the rust-red flour beetle, although they are members of different families and look quite different. The common name of one of these ought to be changed.
Laemophloeus minutus (Olivier)  

This insect is more of a scavenger than anything else, according to Cotton (1941). It is often found by the thousands in elevator boots in stock that is damp or going out of condition, and frequently it is found in large numbers in the sifters. It is not a primary pest of grain. In order for grains to be attacked by this species, they must be injured in some way. It is known to follow up the attacks of more vigorous grain pests such as the rice weevil, with which it is frequently found in large numbers.

According to Blake (1943), the genus Laemophloeus contains about 325 species, most of which damage grain and other plant products. The genus is extremely cosmopolitan in distribution.

This species is one of the smallest insects found in stored grain. The beetle is minute, flattened, oblong, and reddish-brown, and its length is about 1/16 inch. The antennae are about 2/3 the length of the body.

The adult female drops the small white eggs loosely in farinaceous material or in crevices in the grain. It is known that the larvae especially seek out the germ in the wheat kernels. In infested grain, it is common to find many kernels uninjured except for the removal of the germ. The larvae also consume dead insects. A gelatinous substance is formed by the larvae into cocoons. Food particles adhere to this sticky substance. Five weeks may be sufficient to
permit a full developmental cycle under favorable conditions. Usually in summer, however, a period of about nine weeks is required.

Laemophloeus turcicus Grouvelle

This insect closely resembles the flat grain beetle and is naturally closely related. Its habits are similar, and it is also cosmopolitan in distribution. The females of the two species have antennae almost identical in size, and it is almost impossible to distinguish them. In the males of L. turcicus, however, the antennae are as long as the body or even longer. The antennae of the males of L. minutus are, on the other hand, only two-thirds the length of the body.

Lasioderma serricorne (Fab.) Cigarette Beetle Towbug

This beetle, which somewhat resembles the drugstore beetle, is one of the most important pests of tobacco. It attacks cigars, cigarettes, package and chewing tobaccos, and a wide variety of other items, including the following:

| Furniture upholstered in flax, tow, or straw | Rice |
| Cottonseed and cottonseed meal                | Corn |
| Beans                                        | Dried bananas |
| Coffee beans                                | Starch |
| Peanuts                                     | Saffron |
| Pumpkin seed                                | Cacao |
| Sugar                                       | Copra |
| Copra                                      | Cayenne pepper |
| Dried figs                                  | Opium |
| Raisins                                     | Curry powder |
| Dried yeast                                 | Ginger |
| Dried fish                                  | Prepared fish food |
| Books                                       | Gun wads |
| Gun wads                                    | Tapestries |
| Prepared fish food                          | Silk |
The adult is oval in outline and of a light brown color. It is only about 1/16 to 1/10 inch in length. The insect has a characteristically humped appearance, because the head and prothorax are bent downward nearly at right angles to the body. The wing covers lack striations, and the antennae are of the same thickness from base to tip. These characteristics serve to distinguish them from the drugstore beetle.

Oval, whitish eggs of about 1/50 inch in length are laid in and around the substance upon which the insects feed. In 6 to 10 days at summer temperatures, these eggs hatch into yellowish-white, C-shaped, hairy larvae with light brown heads. Fully mature larvae are close to 1/6 inch long. They require 30 to 50 days to reach this stage. According to Blake (1943), young larvae can penetrate twill, packing paper, sisalkraft, paper, and cellophane. The pupal stage lasts for 8 to 10 days or more. It takes place in silken cocoons covered with particles of food material. The adult females may lay as many as 100 eggs during the 2- to 4-week life of the adult. The entire life cycle may require only 6 to 8 weeks. Usually there are from 3 to 6 generations a year.

According to Blake (1943), the optimum temperature is 90° F., the optimum relative humidity 75%. The lowest temperature this insect will tolerate is 55° F., the lowest relative
humidity 30 to 45%. The insects are killed in 2 hours at 130° F. and in 15 minutes at 140° F. At 25° F., they require 7 days before they succumb. Keeping infested items at 140° to 145° F. for a few hours will effectively control them.

*Necrobia rufipes* De Geer  
Red-Legged Ham Beetle  
Copra Beetle

Blake (1943) suggests that the Cleridae, and especially the genus *Necrobia*, are adapted to feeding on insects occurring in burrows. From this predaceous habit they have, to some extent, tended to attack the materials upon which their original prey were feeding. In other cases, they attacked animal products.

This beetle is the most destructive pest attacking well-cured and dried smoked meats. Occasionally it ruins large quantities of hams and bacons. Most of the damage is done by the larvae boring through the fatty portions of the meat, although the larvae also attack the lean portions. The adults are also active feeders.

Blake suggests that this insect probably once attacked Dermestids. Most of the materials the beetle feeds upon now are rather oily and are often rancid. The beetle seems to be especially attracted to rancid fat. Among the foods attacked are the following:
The animals are brilliant greenish blue, convex, straight-sided, noticeably "punctured" beetles. They are about 1/7 to 1/4 inch long and less than half as wide. The legs and the bases of the antennae are reddish brown. The adults are ordinarily seen running rapidly, although they are capable of flight. According to Blake, the adults have a strong tendency to wander. Elongate, cylindrical eggs are deposited in dry recesses of the food substances. Hatching takes place in from four to five days in warm weather. The larvae are long, slender, and tapering toward the head. They possess three pairs of short legs and have short hairs on their body. The body color is purplish. When full-grown, the larvae are about 2/5 inch long. These larvae are strongly repelled by light, as would be expected in view of their burrowing habit. The larvae migrate from greasy foods to dry dark spots to pupate. The pupa, unlike the case in most beetles, is enclosed in a net-like silken cocoon, which it lays down in a crevice.

The life cycle requires slightly over a month in warm weather, to about 150 days in cooler weather. This beetle is nearly cosmopolitan in distribution. It is especially troublesome in the Middle Atlantic States.
Oryzaephilus surinamensis (L.)  
Saw-Toothed Grain Beetle  
Corn silvanis

This is another well-known cosmopolitan grain pest. The name *surinamensis* was given to it by Linne, who received specimens of it from Surinam. For that reason, it was called *surinamensis* in 1767.

It is amusing to note the usual lay understanding of the word "saw-toothed". The average person, when told that this insect is one commonly found infesting packaged foods, pictures the insect as one with extremely efficacious jagged mandibles or "teeth". He pictures it as an insect that can readily penetrate packaging materials. This is far from being the case, for the insect is a poor penetrator. The popular name is misleading, for the word "saw-toothed" applies to the characteristically serrated thorax, which bears six tooth-like projections on each side.

The adults are flattened, slender, small, red-brown beetles. The length is about 1/10 inch. These adults live from 6 to 10 months under typical conditions. However, some individuals have lived as long as three years. Only the adult stage winters in unheated buildings. These adults almost never fly.

Each female lays from 43 to 285 eggs, which are dropped loosely among the foodstuffs or are tucked away in a crevice in a kernel of grain. Hatching of the eggs takes place in 3 to 5 days. The eggs are small, slender, and white, and the larvae developing from them are brown-headed,
elongate, white, six-legged grubs with the abdomen tapering toward the tip. They crawl around freely, not confining their activities to any single kernel. In about 2 weeks in summer, and up to 10 weeks at other times, they become full-grown and reach a length of $\frac{1}{8}$ inch. When they are mature, a protective covering is formed by sticking together small bits of the food material with a sticky secretion. The pupal stage lasts from 6 to 21 days, but a week is typical. Development from egg to adult may take place in from 3 to 4 weeks in summer. Usually there are from 4 to 6 generations a year in the United States. Under favorable conditions, the entire life cycle may be passed in from 24 to 30 days. Ordinarily it requires about 50 days.

The insect feeds on a wide variety of products including all grain and grain products, breakfast foods, nuts, seeds, yeast, sugar, candy, tobacco, snuff, dried meats, dried fruits, and, in fact, almost all plant products used for human food. According to Blake (1943), it is not particularly likely to attack entirely uninjured seeds in natural condition nor animal products in general. Usually it is found in processed materials. The optimum moisture content is about 18% and the optimum relative humidity 70% or more. The insect is killed in 2 hours at $122^\circ$ F. and in 7 days at $20^\circ$ to $25^\circ$ F., and in one day at $0^\circ$ to $5^\circ$ F. It is one of the few insects that can be killed with some degree of certainty by refrigeration.
According to Michelbacher (1947), who tested this insect against a large number of packaging materials, the insects are not effective package or package material penetrators. They failed to penetrate any of the packages Michelbacher tested that were "insect-tight". The latter term probably refers to the fact that no loose flaps or openings were present to permit the insects to gain easy access to the interior of the package.

*Ptinus fur* (L.) White-Marked Spider Beetle

This insect is similar to all spider beetles (*Ptinidae*) in being small, dark, with the head and first thoracic segment much narrower than the rest of the body, which may be cylindrical but is more often broadly oval. A spidery appearance results from the combination of an oval, almost globular body, with long, slender legs. The antennae arise close to each other at the front of the head and are thread- or bead-like.

The white-marked spider beetle is about 1/8 inch long and of a reddish brown color, with four white marks on the elytra. The small, curved, short-legged larvae are white in color. They form globular cases of the material in which they are feeding. This beetle is an omnivorous feeder. It attacks many substances, including fur, which may be responsible for its specific name. Among these are:

- cereals
- ginger
- dates
- paprika
- cacao
- leather
- wool
- bread
- pastry
- skins
- barley
- cottonseed
This beetle winters in the adult and larval stages. The eggs are deposited in the spring. Some of the larvae do not transform to pupae until the following spring; others transform in the fall to the pupal and later to the adult form.

The developmental cycle usually takes about 3-1/2 months. Ordinarily there is only one generation a year.

*Ptinus ocellus* Brown  
*Australian Spider Beetle*

This insect is also known by its synonym *P. tectus* Boield. It has only recently been found in this country and is still scarce. As it is commonly mentioned in the literature, it was considered worthy of being described here.

It feeds on a large variety of plant products, many of which are highly poisonous to man, -- along with a number of animal products. Finely powdered materials are utilized by this beetle. Among the food products it attacks are:

- fish meal
- ginger
- cayenne pepper
- paprika
- cereals
- figs
- casein
- malt
- cacao
- raisins
- dried soup
- meal
- stored hops
- dried pears
- corn
- dried yeast
- nutmegs
- dried apricots
- rye
- almonds
- sago flour
- chocolate powder
- soybean meal
- ship biscuits
- prepared fish food

When ready to pupate, the larva will perforate wood, cellophane, and bolting cloth.

Development requires from 9 weeks to 6 months. About 75° F. is the optimum temperature, and 86° F. is the upper
limit for development. A relative humidity of about 50% is needed in the range of 68° to 80° F., which would correspond to an equilibrium moisture content of about 10% in cereals.

Hickin (1942) carried out some interesting packaging studies on this species. He placed previously starved adults in cellophane envelopes, which he then placed in whole meal flour of 60, 70, and 80% equilibrium relative humidity. In all cases they ate through to the foodstuff. Fully fed larvae were able to bite their way through cellophane and bolting silk, but the movement this time was away from the foodstuff in order to permit pupation to take place among debris outside the mass of food.

**Rhizopertha dominica** Fab. Lesser Grain Borer Australian Wheat Weevil

This insect has been called the lesser grain borer in deference to the larger but similar larger grain borer. It is one of the smallest pests found in grains in this country. It is rapidly becoming one of the major pests of stored grains in the United States. It is also called the Australian wheat weevil because of its prevalence in shipments of grain to this country from Australia during World War I. It is a strong flier and, therefore, spreads rapidly. It is believed to have been introduced into the United States about 100 years ago. Although it is widespread all over the world, it prefers warmer climates.
This insect may be readily distinguished from other grain pests by its slender cylindrical form and small size. The color is brown to black, and the length is about 1/8 inch. The width is about 1/32 inch. The large head is bent under the thorax, and the rear end of the body is rather blunt. The antennae are fitted with large, 3-segmented serrate clubs.

It is particularly common in wheat and is one of the most destructive wheat insects. It feeds in both larval and adult stages in the interior of nearly all grains and other substances. These include seeds, drugs, dried roots, and cork. The insects also eat into wood and paper boxes. All the members of the family Bostrichidae have heads turned down under the thorax and are armed with powerful jaws to enable them to cut directly into wood or other tough vegetable material. Essig et al. (1943) showed this insect to be a rather effective packaging material penetrator in adult form. Cotton (1941) considers this insect as effective a penetrator as the cadelle.

This is one of the two test insects prescribed by T.A.P.P.I. for its insect resistance test (T.A.P.P.I., 1947). It is the opinion of the author, however, that it is an ill-advised choice, for there are better test insects described in the literature. The author is a member of the committee charged with responsibility for this test and is in a position to suggest a change.
The larvae of this species do not require whole seeds in which to develop, as do the larvae of grain weevils. For this reason they are not limited to whole grains, but may also infest processed cereals such as flour. They are, however, most commonly found among whole grains, where the eggs are laid among the kernels. The larvae then feed on the "millings" of the adults or bore into the kernels. The adults, further described above, lack the prominent proboscis of the weevils. They move about slowly and sluggishly, although they are active fliers. Adult females lay from 300 to 500 eggs each. These are dropped singly or in clusters in grain, and hatch in a few days into small whitish grubs. The pupae are also white.

The entire developmental period in summer is about one month. This short period is probably a consequence of the insect's grain-dwelling habit. Little reproduction occurs below 80° F. The optimum temperature is about 95° F. The insects do not require much moisture. Sometimes it is difficult to detect the presence of these insects, for they frequently take refuge within the infested grains, if cool or disturbed. Warming them will cause them to come out and move about. At a temperature of 122° F. they are killed in 3 minutes (Blake, 1943).
**Sitrodrepa panicea** (L.)

**Drugstore Beetle**

**Drugstore Weevil**

*Stegobium paniceum* (L.) is another name for this insect. Although it has been called the drugstore weevil ([Farmer's Bulletin 1260](#)), it is not a true weevil. The beetle belongs to the family Anobiidae, a family of wood-borers, but, like its close relative, the cigarette beetle or towbug, it attacks almost any dry material except wood. These materials include the following:

- grain and cereal products
- bakers' goods
- yeast cakes
- cereal foods
- seeds
- coffees
- cloth containing glue
- casein
- bamboo
- beans
- peas
- pepper
- chocolate
- ice cream powder
- books
- paste
- leather
- at least 45 different drugs, some of which are poisonous to man

This insect has been said to "eat anything except cast iron". It has been found in storehouses and granaries all over the world.

The drugstore beetle closely resembles the cigarette beetle in appearance, although it is longer, averaging about 1/10 inch. The elytra or wing covers are distinctly striated. The body is cylindrical and of a uniform light brown color. Although the larva is almost hairless, the adult is covered with a fine silky pubescence.

The eggs are laid in almost any dry organic substance. The small white larvae emerge from the eggs and tunnel their
way through these substances. When full-grown, they pupate in small cocoons. The very small larvae are capable of making their way through tiny crevices in a package, where they feed, pupate, and emerge as adults.

The development of this insect is rather slow. It requires from slightly less than two months to 230 days. Generally there is only one generation a year. The optimum temperature is between 79° and 83°F. The larvae, however, are able to survive even the coldest winters because of their ability to hibernate in little cells made out of the food material in which they live.

When the adults leave the food packages in which they have developed, some always remain behind to breed new stocks. For this reason, an infested package is a constant source of trouble and should be destroyed. The adults can readily penetrate board, paper, cork, and cellulose-based plastics, but in only very few cases is infestation caused by insects boring their way into packages and laying their eggs. As with other insects, they more often enter by means of defective package closures.

Michaelbacher (1947) found that, although the insect has fairly well-developed boring habits, it does not have a tendency to bore into packages, but it readily bores out of them. This fact should be considered if this insect is used as a test insect. It also indicates by its presence in food packages that infested material was
packaged. This is an indictment against the packager.

Preliminary experiments by Verdcourt (1947) showed that these insects readily penetrated cellulose-based plastics even at low temperatures. He found, however, that they were able to penetrate polyvinyl chloride (Geon, Koroseal), polyvinyl-chloride-acetate copolymer (Vinylite), polyvinylidene chloride (saran), and rubber hydrochloride (Pliofilm) with more difficulty, even at their optimum temperatures.

Sitophilus granarius (L.)  
**Grainary Weevil**  

Sitophilus oryzae (L.)  
**Rice or Black Weevil**

These two weevils are reported to be among the most destructive grain insects in the entire world. They do a tremendous amount of damage in grain elevators, on ships, and in farmers' bins, frequently causing infested grain to heat at the surface. Sprouting is apt to occur if the grain happens to be damp at the time it is thus heated.

The grainary weevil and the rice weevil, which were for a time grouped in the family Calendridae (now no longer a family), are distinguished from all other beetles by their snout. This snout is an elongation of the head. It accommodates the strong jaws the beetles use in drilling into the endosperm of cereal grains.

Both species spend their entire developmental period inside the grain kernels. The female lays an egg in a small
hole she bores with her long "proboscis" into the kernel. This hole is then sealed with a gelatinous material. It is difficult to detect this opening without the use of a special staining technique, reported elsewhere in this thesis (page 33). A white legless grub develops in the kernel and eats out most of the endosperm as it grows. The development continues within the kernel until such time as the adult weevil emerges. Howe and Oxley (1944) have developed techniques to measure the CO₂ output of samples of grain. They have drawn up a scale of indices for degrees of infestation based on CO₂ output.

These two insects attack a long list of products, including the following: wheat, corn, macaroni, tightly packed flour, buckwheat, barley, acorns, chufa, kaffir seed, ginger, currants, figs, rice, and other grains and grain products. The larvae develop in seeds or pieces of seeds or other cereal products big enough to accommodate them. They do not feed on flours unless they have become caked.

The average adult life expectancy is 4 to 5 months. Adults are reported to be capable of withstanding starvation for as long as 2 or 3 weeks. Quite commonly they live as long as 7 or 8 months, and in some cases have been known to live over 2 years. The entire life cycle may take place in only 4 to 7 weeks under favorable conditions. There may be as many as 4 or 5 generations a year.
Brues (1946) quotes Robinson (1930) as stating that the granary weevil contains 46% of water, half of it in the bound state. Dendy and Elkington (1920) and Robinson (1926) have shown that the rice and granary weevils require a moisture content of at least 8% in wheat if they are to breed normally.
Sitophilus granarius (L.)

Linne described and named this species over 200 years ago, but it had been known considerably longer than that. It grows up to 3/16 inch in size and is also chestnut brown or blackish. Unlike the rice weevil, the granary weevil has so greatly adapted itself to living off man's grains that it has completely lost the ability to fly. Probably this degeneration antedates man, however. The elytra or wing covers are partially fused and, therefore, flight is not possible. It is never found breeding in the field, being found only where grain is stored. The insect is, as indicated, slightly larger than the rice weevil and is characterized by longitudinal instead of round pits or punctures on the thorax. The granary weevil lives slightly longer than the rice weevil, the average life being 7 to 8 months. In general, it is found in more northern climates, although the two species are frequently found side by side. The females lay from 50 to 250 eggs.

The optimum temperature is 77° F., although egg laying takes place between 53-1/2° and 91-1/2° F. Growth and development fail to take place below 50° F., although the adult lives up to 6 weeks at 31° F. Adults are killed at 131° F. in 30 minutes. The larvae fail to mature at relative humidities below 44%. The optimum relative humidity is 93%.
In northern Europe the adults have been known to survive a summer without food.

The granary weevil is generally reported to be nearly as efficient a package penetrator as the cadelle larva. Blake (1943) reports observing both the rice and the granary weevil boring through heavy paper covered with lead foil. Michelbacher (1947) unexpectedly found the granary weevil to be a good penetrator of thin packaging materials.

Sitophilus oryzae (L.) Rice Weevil or Black Weevil

According to Cotton (1941), this is the most destructive insect pest of stored grain. In early years it was less known than the granary weevil, although this is no longer the case. Linne described and named this weevil in 1763, after obtaining specimens from Surinam. The name oryzae refers to the fact that the insect was found breeding on rice. Only in recent years has the rice weevil become predominant in this country.

The insect is about 1/8 inch long and of a dark chestnut brown to blackish color. It is slightly smaller than the granary weevil and is characterized by four light reddish or yellowish spots, one at each end of each elytron. The rice weevil, as opposed to the granary weevil, still retains its wings, and in the South, especially in warm weather, flies from granaries or other sources of grain to the fields, where it starts new infestations. It is reported to be a strong flier, although this writer has never succeeded in getting any rice weevil to fly, even when
capturing it from outside grain-filled burlap bags. Cotton reports that about 10% of the corn crop of the South is destroyed each year by the rice weevil. In the North this insect is found around old grain and in and around granaries, bins, and elevators. It starts infestations of new grains rapidly. The rice weevil is generally a more Southern pest than the granary weevil.

The author found a number of these weevils crawling over bags of corn in March of 1950. At the time a few confused flour beetles were also found. Two months later scarcely a rice weevil could be found, and the corn was overrun with confused flour beetles. No satisfactory explanation for the disappearance of living rice weevils could be found -- unless hand picking of these weevils two months earlier had almost entirely eliminated them.

The thorax of the rice weevil is densely pitted with round instead of longitudinal pits, as in the granary weevil. This serves as an accurate means of identification to supplement the yellowish spots mentioned above.

According to Blake (1943), the dietary of this insect is about the same as that of the granary weevil. It is capable of surviving under drier conditions than the latter, however, for its optimum relative humidity is below 56%, as opposed to 93% in the granary weevil. The rice weevil can also withstand higher temperatures, the optimum being 84° F. as compared with 77° F. for the granary weevil. As it favors higher temperatures, it is less apt to be found in cool Northern regions.
**Tenebrio molitor (L.)**  

Yellow Mealworm

This insect, along with the dark mealworm which it closely resembles, is one of the largest insects found in dried cereal products. The name comes from the larva, which is of a honey-yellow color. These larvae are about an inch long at maturity. The body is cylindrical and glossy and much resembles a wireworm.

The large black adults are frequently called darkling beetles, as are the adults of the dark mealworm. The adults are dark brown or black and are about one-half inch in length. The thorax is finely punctured and the elytra longitudinally striated or grooved. Bean-shaped white eggs are laid, which are covered with a sticky secretion that attracts the grain they are found in. The eggs require about two weeks to hatch into slender white larvae that eventually develop into the characteristic yellow larvae. As many as 500 eggs are laid by each female. About three months are required for the larvae to reach full development. This development takes place during the summer. However, instead of the larvae transforming into adults when larval maturity is reached, they continue feeding and molting until winter, when they hibernate in the larval stage. They form pupae in late spring or early summer. After about two weeks in the pupal form, the adult emerges. Eggs are then laid by adult females, and the cycle starts again. Obviously there is only one generation a year,
which is unusual for stored-food product insects. Most of them complete their development in about a month under favorable conditions.

Because of this long developmental period and because the mealworm is entirely an external feeder on grains, it is not a serious pest. Mealworms are extremely omnivorous. They feed on all forms of cereals and also such materials as feathers, dead insects, and meat scrap (Smallman, 1945). They seem to prefer cereal products that are somewhat spoiled to fresh products and are commonly found in dark, damp places that have been undisturbed for long periods of time. Smallman points out that in warehouses they may breed in large numbers beneath floors where they feed on cereal materials that sift through. Although they cause no direct damage in this way, the mature larvae tend to invade bags of grains or bales of finished products, looking for a place to pupate.

It is important to note that, because of the slow development and because these insects are found only in out-of-condition grains, the presence of mealworms indicates poor construction or negligence in ordinary cleaning practice, with the result that cereal materials have been allowed to accumulate in out-of-the-way places.

Valentine (1931) carried out some rather interesting experiments on the olfactory sense of the adult of this
species. His conclusions throw light on the mechanism of attraction to foods. The olfactory organs are located chiefly in the terminal four segments of the antennae. The sense organs through which Tenebrio receive the odor of food (aqueous bean extract) are identical with those operative with perception of the odor of other individuals. Experiments on beetles with sectioned palpi indicated that the peg organ-like sensilla at the distal ends have a gustatory rather than an olfactory function. Valentine also showed that males and females have distinctively different sexual odors, both of which differ from the musky odor perceptible when either sex is handled. The latter is probably simply an offensive mechanism used for protection.

It is simple to tell, without morphological examination, whether an adult is male or female, by the attitude of the beetle toward another member of the same sex. These actions are distinctive.

According to Valentine, the sensory organs are located primarily on the antennae. The olfactory organs (peg organs), including those concerned with sexual attraction, are located in the terminal four segments of the antennae. Peg organs on males are slightly superior to those on females.

T. molitor is less common in the southern states than is T. obscurus. Under very unusual conditions, the life cycle may be as short as 4 months or as long as nearly 2 years (U.S.D.A. Tech. Bul. 95, 1929).
T. molitor is commonly raised as food for small insectivorous animals. According to Blake (1943), the optimum temperature is about 80° F., and the larvae and adults may be killed in a reasonable time at 10° F. and 125° F. This same authority states that the larvae show considerable powers of penetration, going through paper and boring into wood.

_Tenebrio obscurus_ (Fab.)  
Dark Mealworm

In general, the discussion for the dark mealworm is just about the same as that for the yellow mealworm. However, the adult in the former is a dull, pitchy black, and the larva is dark brown rather than yellow or yellowish brown.

The overwintering or hibernating larvae of the dark mealworm begin to pupate earlier in the season than do those of the yellow mealworm, and the adult beetles emerge somewhat earlier (Back and Cotton, 1940). Often both species are found associated, which is to be expected, for they have similar feeding habits.
This beetle is one of the best-known stored grain pests in the United States. The family Ostomatidae consists almost entirely of New World beetles, and it is thought by some that the cadelle is a native of America. Linné described the cadelle in 1758. At present it is extremely cosmopolitan. The adult is elongate, oblong, flattened, and black or blackish in color and of about one-third inch in length. The large fleshy larvae grow to one-half to three-quarters of an inch in length. Depending upon the conditions, the larvae require from 70 days to about 14 months to complete their development. Some have been kept alive for nearly three and one-half years.

About one thousand eggs are laid, usually in groups of 10 to 60, on or near the food. The females oviposit during most of their lives. The eggs are most commonly found in cracks, under flaps of cartons, or in some such protected situation. About one or two weeks after the eggs are laid, they hatch into rather soft-bodied, white to grayish-white larvae. These larvae have prominent black heads, black spots on the three thoracic segments just behind the head, and two short dark terminal hooks at the rear end of the body. Mature larvae seek some secluded space in which to pupate. They frequently bore into the timbers of the bin or other receptacle holding the infested
material. The adults are also capable of boring and hiding in this same manner. Both the larvae and the adults can live for considerable periods without food. Frequently they do this, remaining in the woodwork of bins after the grain has been removed and coming out to infest newly stored grains. The life of the adult female is about a year.

This insect is easily distinguished from the mealworm adult by the smaller size and daintier appearance of the cadelle. The head and prothorax in the cadelle are distinctly separated from the rest of the body, to which they are attached by a loose prominent joint. By means of this joint the anterior region of the cadelle can be twisted considerably. This extra flexibility may be of extreme value in boring operations in small, confined spaces.

The name "bolting cloth beetle" is sometimes given to this insect because of its habit of cutting the silk cloths of bolting reels and redressing machines in flour mills.

The cadelle, especially the larva, is one of the most efficient package and packaging material penetrating insects known. For this reason, it is commonly used in testing the resistance of these materials to insects in general.

According to Blake (1943), the optimum temperature is about 82°F., but the larvae and adults will withstand freezing temperatures for some days.

The author has had an opportunity of finding adult cadelles infesting a shipment of corn.
The rust-red flour beetle, formerly known as *Tribolium ferrugineum* (Mulsant), is second only to *T. confusum* as a nuisance in ground cereal products. According to Cotton (1941), this beetle has been known since 1797, long before *T. confusum*. It is impossible to distinguish the two species without the aid of a magnifying glass. The easiest way of distinguishing the two is to study the structure or shape of the head and the antennae. In *T. confusum*, the segments of the antennae increase gradually in size from the base to the tip. On the other hand, the antennae of the rust-red species have the last three segments much larger than the ones just preceding, and consequently the enlargement at the tip seems much more abrupt.

In the case of the rust-red species, the margins of the head are nearly continuous at the eyes. On the other hand, in *T. confusum* they are expanded and notched at the eyes.

Both *T. confusum* and *T. castaneum* are frequently found together, and their habits are very similar. *T. castaneum* has a somewhat shorter developmental period, according to Back and Cotton (1940). This insect, like the confused flour beetle, imparts a nauseous smell and taste to the grains it infests. It is generally found in more southern habitats than the confused flour beetle. This may account for the shorter developmental period, for insects found in warmer climates are apt to have faster rates of development.
**Tribolium confusum** (Jacq. Duval) Confused Flour Beetle

This insect is probably the most commonly found insect wherever flour in any form is found. Although it is probably not a primary invader, it nevertheless gives the food industry considerable trouble, for once it establishes itself it seems to thrive under the poorest of conditions. The adults are about 1/7 inch long, elongated and reddish brown. The larvae are brownish-white, somewhat flattened, with legs apparent. (Metcalf and Flint, 1939). All kinds of grains are attacked, along with flour, starchy materials, beans, peas, baking powder, ginger, dried plant roots, drugs, snuff, cayenne pepper, and many other foods. This insect, which was first noticed in this country in 1893, occurs throughout the world.

The adults are very active and move rapidly when disturbed. Very small white and clear eggs are deposited on sacks, in cracks, or directly on the food, and hatch in five days into small brownish-white worms (Metcalf and Flint, 1939). According to Brindley (1930), these larvae are 1.18 mm. in length and 0.18 mm. across the head capsule, in the first instar. The sixth instar is reached after 15 days. At this time the length is 6.00 mm. and the width of the head capsule is 0.53 mm. It is easy to see how a first instar insect larvae with a head capsule about 1/5 mm. in width can work its way through small openings with relative facility.
The males, in general, are slightly smaller than the females, but it is not possible to determine sex accurately in the adult. The adults usually live from two to nearly four years (Park, 1934). Newly emerged adults can be readily distinguished by their lighter red color, whereas old adults are almost black.

These insects cannot feed on whole grains because their mouthparts are not adapted to feeding on large particles of food. The adults, however, prefer bran to fines. Apparently they prefer a coarse material that they can enter readily and through which they can move with facility. (Park, 1934). The adults are photonegative and react negatively to gravity in that they tend to climb up vertical surfaces. The females lay about 400 to 500 eggs. The period from egg to adult in summer averages about six weeks, when weather conditions are optimum. The life cycle is greatly prolonged by cold weather.

It is known that the adult beetles give off an aldehyde-like odor when stimulated, especially by rubbing. This gas is very objectionable to man. It has also been found to inhibit the transformation from larvae to pupae and from pupae to adults (Chapman, 1926).

According to Blake (1950), this odor when overconcentrated keeps the insects uniformly separated in the food medium. Recently the Quartermaster Corps laboratories have been attempting to identify and synthesize the chemical
forming the odor. The object is to produce a new repellent.

These insects are able to stand extremely low humidity conditions for long periods of time. Fortunately they do not fly.

According to Good (1933), beetles of the subfamily Ulominae, of which Tribolium is a member, occur either as pests of stored products or else under the bark of trees and in rotting logs. Apparently the members of this group were originally found in the latter environment. Tribolium madens Charpentier, the black flour beetle, and T. indicum Blair are found almost entirely in forest wood environments. In fact, T. confusum and T. castaneum are themselves occasionally found in these environments.

Blake (1943) states that the insect shows no great power of penetrating materials such as paper or cloth. According to him, reproduction occurs between 80° F. and 102° F., and the required relative humidity is from 65 to 90%. It does not ordinarily live at temperatures below 21° F. or higher than 102° F.

According to Chapman (1931), Tribolium exhibits relatively little olfactory selection of food. The short horny mandibles fragment particles of food; maxillae and maxillary palpi aid in the process and also work the material into the mouth proper. Chapman states that #9 silk bolting cloth will pass no eggs; #3 cloth separates eggs and larval stages from flour; #000 cloth passes all eggs and larvae except the last instar forms.
H. Order HYMENOPTERA

Monomorium destructor

This species of ant is mentioned here, not so much because it attacks a wide variety of foods but because it has extraordinary penetrating powers. According to Blake (1943), it is found throughout the tropics and in the southern United States.

In general, it prefers animal to vegetable food, but it will take sugar readily. The ant also attacks cloths and fabrics and will voluntarily bore into cement. It is capable of boring a hole almost a millimeter thick in lead. Frequently this ant has been found damaging electrical material, including both insulation on the wire and lead sheathing on the cables. It is one of the few insects that will attack rubber.

The nests of *M. destructor* are built in wall crevices.

I. Order DIPTERA

*Piophila casei* (L). Cheese or Ham Skipper

The adults of the cheese skipper are small, shiny, two-winged flies slightly less than 1/6 inch long. The eggs are laid singly or in clusters up to about 50 in number, and hatch in from 1 to 1-1/2 days into small fleshy maggots. These larvae taper toward the anterior end and are without legs. They are yellowish-white in color and about 1/3 inch long at larval maturity. One week to several months may be required to complete larval growth, after
which the larvae change into very light brown puparia. They remain in the puparium for from one week to ten days. On the average, about 18 days are required for the entire life cycle.

The larvae crawl in and about cheese or meat and jump or "skip" for short distances by bending their bodies nearly double, seizing their "tail" by the mouth hooks, and then suddenly straightening.

This insect pest is world-wide in distribution. Usually it is found only in cured or smoked meats, for other types of meats are not usually left around exposed very long. It has been found in ham, salt pork, stored beef, cured fish, green hides, bones, cheese, and oleo-margarine. Generally it avoids fats, however.

The maggots are known to be extremely resistant, both to temperature and insecticides. They are capable of withstanding temperatures anywhere between -8° and +131° F. They are killed at 126.5° F. in one hour. The optimum relative humidity is 60%.
VI. EXPERIMENTAL WORK

Several cultures of package-infesting insects were sent to the author by the Biological Laboratories of the Philadelphia Quartermaster Depot. These cultures, along with a few others that had been sent to the Food Technology Department of the Massachusetts Institute of Technology, were the primary source of test insects for this study. All the specimens of cadelles used were found locally in infested corn. The cadelles were all adults and were identified by the author. Unfortunately no cadelle larvae could be found. It will be recalled that the cadelle larva is considered just about the best packaging material penetrator known. In the same shipment of corn were found rice weevils, confused flour beetles, several moth larvae and adults, an unidentified Dermestid beetle, and a single flat grain beetle. The adult moths could not be captured, and the author was not quite sure of their identity. Nor could he be sure of the species represented by the few moth larvae that were found. Nevertheless, the latter were used as test insects in this work.

In laboratories doing a great deal of entomological work, facilities are usually available for maintaining optimum conditions of temperature and humidity, and much attention is given to the use of the best possible food medium for the insects. Adults, larvae, and eggs are
frequently separated, and dead insects are removed. Cannibalistic species, like the cadelle, must be watched closely. However, in maintaining test insects for use in this investigation, the insects could not be nursed along. For this reason, several of the species that were originally to be used became decimated and had to be discarded.

The following species were still available and were used:

- *Tenebroides mauritanicus* (L.) Cadelle (adults)
- *Tribolium confusum* Jacq. Duval Confused Flour Beetle (adults and larvae)
- *Tribolium castaneum* Herbst Rust-Red Flour Beetle (adults)
- *Tenebrio obscurus* (Fab.) Dark Mealworm (larvae)
- *Dermestes ater* De Geer Black Larder Beetle (adults)
- *Attagenus piceus* Olivier Black Carpet Beetle (larvae)
- *Anthrenus vorax* Waterhouse Furniture Carpet Beetle (larvae)

For test materials the following sheets and films were used:

- KVP 27-pound crinkled parchment (white)
- KVP 27-pound parchment (yellow)
- Towelling paper
- Toilet tissue paper
- 2-ply glassine
- Sylvania 450 P.M.B. 6.
- Plax .001" polyethylene
- Plax .003" polyethylene
- 75 NO Pliofilm
- 50-gauge Saran 517
- 100-gauge Saran 517
- GSX Cellophane
  - Polyethylene-kraft-polyethylene
  - Polyethylene-coated Kraft paper
  - Aluminum foil-board laminate
  - Aluminum foil-paper laminate
In carrying out the first part of the experimental work, it was decided to use the technique of Derby (Proctor and Sluder, 1942-44), with some modifications. (See p. 37 for brief description of Derby's method.) Two different sized crystallizing dish assemblies were used, depending largely upon the number of test insects available. (See Fig. 55.) These dishes were obtained locally from a scientific supply house. They are identified by the Kimble # 23000. The smaller dishes were 50 mm. in diameter and 35 mm. high; the larger dishes were 125 mm. in diameter and 65 mm. high. The test sheets or films were cut out with a pair of scissors to a diameter slightly larger than the dish diameter.

A small amount of appropriate food was placed in the dish selected for use as the bottom chamber. For example, in a cadelle test, about 7 or 8 kernels of corn were used. A piece of wet Du Pont cellulose sponge was placed in the lower chamber in all units. The test sheet or film was mounted in place on top of the lower dish with a few pieces of Scotch tape. A wet piece of sponge was placed in the middle of this disc and the surface of the sheet was sprinkled with a small amount of flour (except in the case of the cadelle). The adults or larvae were placed on the sheet surface, and the glass cover was quickly placed in position before the insects could escape. The top dish was secured to the lower dish with Scotch tape, which also helped to keep the test sheet in position. Appropriate labels were then placed on all units. The test units were kept in a frequently-used
laboratory on a table. No attempt was made to keep the insects in the dark. The average temperature during the test was probably about 27° C.

The sponges were used to increase the relative humidity somewhat, for it was felt that frequently test insects die from desiccation before they have an opportunity to show their penetrating ability. The effect of the high humidity of the sponge was found to be only temporary, however, for even in the small units the sponges could be seen to be completely dry in several days. This was an indication that the test units were not completely air-tight. Air was apparently getting in and out through the space between the edges of the glass test units and the test sheets. This was perhaps fortunate, for it was then certain that the insects were obtaining sufficient oxygen to permit them to carry out normal metabolic activities.

Because both the larvae and the adults of the cadelle are known to be capable of surviving long periods without the use of food, no flour or other food was placed on the insect side of the test sheet. It was thought that the incentive for the adults to penetrate the sheet would in this way be greater.

In all test units the insects being tested could probably either see or smell the food incentive in the lower chamber. In some cases they could probably do both. In the case of the saran and cellophane barriers, it is
unlikely that these materials transmitted the food odors, but they are highly transparent. The opaque papers were probably all permeable to food odors.

For the second part of the experimental work, it was decided to use mealworms and cadelles (adults). Screw-type Mason jars were used for one type of test; sealed envelopes were used for the second type. The object was to determine whether the insects were able to attack the creased surface of the bags or packets more easily than the relatively smooth surface of the sheet in the Mason jar assembly.

With the Mason jar assembly, flour was placed in a petri dish and a Mason jar with a film or sheet across the mouth, held in place by the screw cap. (See Figs. 61 and 62.) Three test insects were placed inside each Mason jar. The insects, if they were able to bore through the sheet, were able to escape into the flour in the petri dish. A wet cellulose sponge was placed in each Mason jar along with the insects. For cadelles, corn kernels were used instead of flour.

With the bags or packets, heat sealing was used where practicable. If heat sealing could not be used, the bags were sealed with Scotch tape. The bags were about 2" x 3" and were filled with flour for mealworms and corn kernels for cadelles. (See Figs. 59 and 60.) The bags were placed in mayonnaise jars, each holding three insects, and in the case of the mealworms a small amount of flour. No corn was placed
in the jars with the cadelles, for they are capable of undergoing long periods without food. The object was for the test insects to eat their way through the packets.

VII. RESULTS

The results are summarized as follows:

Crystallizing dish technique

**Cadelle adults**

- Pliofilm: no penetration
- Polyethylene: no penetration
- Cellophane: no penetration
- Saran: no penetration
- Crinkled parchment: no penetration
- Plain parchment (yellow): no penetration
- Aluminum foil-board laminate (with cut through flap lying flush): 2 days to get through flap
- Toilet tissue paper: 8 days
- Toweling paper: 3 days
- Polyethylene-coated kraft paper (paper side up): partial penetration up to the polyethylene

(All were small units with 2 insects each, with the exception of the aluminum foil-paper laminate, which was a large unit with 4 insects.)

**Mealworm larvae**

- Crinkled parchment (large unit with 6 insects): 4-1/2 days - 2 holes

**Confused flour beetle adults**

- Toilet tissue: no penetration
- Toilet tissue, folded (large unit with 6 insects): no penetration

**Confused flour beetle larvae**

- Toilet tissue paper (small unit with 6 larvae): no penetration

**Black larder beetle adult**

- Crinkled parchment (small unit with single adult): no penetration
(Rice 1) moth larva

- toilet tissue (small unit with single larva) no penetration

Furniture carpet beetle larvae

- toilet tissue (large unit with 6 larvae) no penetration

Black carpet beetle larvae

- toilet tissue no penetration

Rust-red flour beetle adults

- toilet tissue no penetration

The above tests were carried out for as long as 30 days in cases where no penetrations were obtained.

Mason jar and bag techniques

<table>
<thead>
<tr>
<th>Materials</th>
<th>Jar Tests</th>
<th>Bag Tests</th>
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<tbody>
<tr>
<td></td>
<td>Mealworms</td>
<td>Cadelles</td>
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<td>2-ply glassine</td>
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<td>0</td>
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<td>100 gauge Saran 517</td>
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<tr>
<td>onion skin paper</td>
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<td>6 hrs.</td>
</tr>
</tbody>
</table>

(tests were continued for a total of 4 weeks)

* .0025" polyethylene.
VIII. DISCUSSION

It was found that the cellulose sponges dried out rapidly. In the case of crystallizing dish units not showing penetrations within five or six days, it was found necessary to re-wet the cellulose sponges occasionally in order to prevent desiccation of the adults or larvae. The author believes that any insect, whether adult or larval form, which is not capable of penetrating toilet tissue, is not likely to be able to penetrate any kind of packaging material unless some kind of access is already present. It was for this reason that such an unconventional material as toilet tissue was used in these tests. The reader will note that this material was the only material tested in the two flour beetle, the carpet beetle, and the moth larva units, none of which were expected to show penetrations. Fig. 58 in the Appendix shows the porous nature of this tissue, in addition to holes effected by the cadelle adults. It is interesting to note that one cadelle succeeded in getting through the paper by working its way under a piece of Scotch tape pasted across the sheet. With its back directly under the tape, it was probably able to use the tape to good advantage in enabling it to obtain a good firm position while boring. The adhesive on the tape apparently was no great deterrent. This opening, which was the first one on this particular sheet, was in the form of a slit rather than a hole. In the photograph it is clearly visible as a
slit. It is significant that the other test insects penetrated the film through their own efforts rather than through the same slit as their predecessor.

Apparently the transparent films were penetrated in only a few cases, even though some of them were very thin. The results indicate that it is quite probable that the insects are much more capable of penetrating these "plastic" films when a creased surface is available to them. Where a perfectly smooth surface is presented, they are unable to do so. The cadelles, for example, were seen to slip and slide on these films, and when they were on their backs, it was only with difficulty that they were able to regain their feet.

It is unlikely that the cadelles would have been able to penetrate the foil-board laminate, except possibly over a long period of time. That they were able to do so in two days was only because of the presence of the cut flap, on which they proceeded to work.

Most of the penetrations in crystallizing dish units were found on the periphery of the test disc. This is due to the nature of the insects to attempt to escape by radiating outward from the center of their "prison". When they meet the glass wall, they then proceed to wander around it, now and then making an attempt to break through. In time they are apt to find a spot where the paper is a little bit thinner
or where there is some imperfection present, of which they can take advantage. Even where one insect succeeds in breaking through the test barriers, all the other test insects do not immediately follow suit. Rather they go on exploring and eventually stumble upon the means of escape that their mates have previously located. In some cases, as was shown above, several holes were found, any one of which was sufficient to permit passage of the insect body. Apparently the later insects succeeded in boring holes of their own before they found other holes already present.

The author was not at all surprised to see no penetrations by either adult or larval Tribolium species. It is his personal belief that these insects are solely secondary invaders. The same probably holds for the Dermestid larvae studied. However, if larder beetle larvae were present, it is likely that they would be found efficient penetrators, as mentioned above. Nothing conclusive was expected to be learned from the single Dermestes ater De Geer adult studied, but it was used nonetheless, for it was the only live insect found left in the culture of this particular Larder beetle.

The writer was extremely impressed by the clearly defined holes cut by the mealworm larvae.

The cadelles were able to cut through the kraft paper-polyethylene laminate up to the polyethylene. That they were stopped here speaks well for this particular plastic film. However, mealworms were able to penetrate a .0025" polyethylene bag very readily.
IX. CONCLUSIONS

Although the above tests should be regarded largely as screening tests, nevertheless certain conclusions can be drawn from the work. In general, it was found that:

1. Tribolium spp. appear to be incapable of penetrating even the simplest continuous barriers, even in the larval form.

2. Cadelle adults appear to be good penetrators.

3. Mealworm larvae appear to be excellent penetrators.

4. Carpet beetle (Dermestid) larvae also appear to be incapable of penetrating the simplest barriers.

5. No "plastic" film present as a continuous barrier was penetrated by any form in crystallizing dish units. It is probable that the insects are unable to obtain a satisfactory foothold on these materials. On the other hand, successful penetrations were made in bag units.
X. RECOMMENDATIONS FOR FURTHER WORK

1. More work should be done on several typical varieties of material with mealworm larvae.

2. Further work should be done along the same lines with the cadelle adults. A considerable amount of work has already been done by various authorities with the larvae of this species.

3. Further work should be done with termites, which have been shown to be extremely efficient penetrators.

4. If at all possible, rooms of constant temperature and constant humidity should be used.
XI. REMARKS

The photographs in this thesis noted as original were taken in part with a Leica camera with an f 3.5 Summar lens with a Speed-0-Copy device, and in part with a Praktiflex camera with an f 2.9 Viotar lens, along with a microscope adapter. Extension rings were used in both cameras.

Any photographic copies of non-original work or drawings were made with the Praktiflex with extension rings. This camera was found to be extremely useful for both copying and photomicrography, because of its built-in reflex focusing. The Leica, although giving excellent results, required the use of the Speed-0-Copy device.
XII. APPENDIX

A. Systematic List of Insects and Other Arthropods Infesting Foods and Food Products

Class ARACHNIDA - Spiders, Ticks, and Relatives
Order ACARINA - Mites and Ticks
Family - Tyroglyphidae
  Tyroglyphus farinae De Geer
  Tyroglyphus longior Gerv.
  Acarus siro (L).

Class INSECTA - Insects
Order THYSANURA - Silverfish and allies
Family - Lepismatidae
  Ctenolepisma quadriseriata (Packard)
  Ctenolepisma urbana
  Lepisma saccharina (L.)
  Thermobia domestica (Packard)

Order ORTHOPTERA - Roaches, grasshoppers, crickets, allies
Family - Blattidae - Roaches
  Blatella germanica (L.)
  Blatella vagia
  Blatta orientalis (L.)
  Periplaneta americana (L)
  Periplaneta australasiae (Fab.)
  Periplaneta fuliginosa (Serville)
  Supella supellactilum (Serville)
Family - Gryllidae - Crickets

- Gryllus assimilis (Fab.) Common field cricket
- Gryllus domesticus (L.) House cricket
- Gryllus of the hearth

Order DERMAPTERA - Earwigs

- Anisolabis annulipes Ring-legged earwig
- Prolabis arachidis Brown earwig

Order ISOPTERA - Termites

Family - Kalotermitidae - Dry wood and damp wood termites

- Kalotermes castaneus Southern dry wood termite
- Kalotermes hubbardi Common dry wood termite
- Kalotermes minor
- Kalotermes schwarzi
- Zootermopsis angusticollis Common damp wood termite
- Zootermopsis nevadensis Nevada damp wood termite

Family - Rhinotermitidae - Subterranean termites

- Leucotermes aureus Desert subterranean termite
- Reticulitermes hesperus Western subterranean termite
- Reticulitermes humilis
- Reticulitermes virginicus
- Reticulitermes flavipes Eastern subterranean termite

Family - Termitidae

- Amitermes minimus Wheeler's desert termite
- Amitermes wheeleri
- Nasutitermes nigricans Haldeman's black nasute
- Nasutitermes mexicanus Mexican yellow-headed nasute
Order CORRODENTIA (= PSOCOPTERA) - Psocids, booklice, and allies

Family - Psocidae - Psocids or barklice

Lachesilla pedicularia
Lepinotus patruelis

Family - Trogiidae - Booklice and allies

Troctes divinatoria Müll. Common booklouse
Trogium pulsatorium (L.) Death watch

Order LEPIDOPTERA - Moths and butterflies

Family - Arctiidae

Celama sorghiella

Family - Cosmopterygidae

Pyroderes rileyi (Walsingham) Pink corn worm

Family - Gelechiidae - Gelechiid moths

Sitotroga cerealella (Olivier) Angoumois grain moth
Phthorimaea operculella Zell. Potato tuber moth

Family - Oecophoridae

Endrosis saritella (L.) White-shoulde red house moth

Hofmannophila pseudospretella (Stainton) Brown house moth, false clothes moth, seed moth, American clothes moth

Family - Phycitidae - Phycitid moths

Ephestia cautella (Walker) Almond or fig moth, dried currant moth
Ephestia elutella (Hübner) Tobacco or chocolate moth, cacao moth
Ephestia figuliella Gregson Raisin moth
Ephestia sacchararium (Scott) Mediterranean flour moth, mill moth (formerly E. Kushniella Zeller)
Ephestiodes nigrella Dried fruit moth
Vitula edmandsii (Packard)
Family - Pyralididae - Pyralid moths
Aglossa caprealis (Hübner)
Corcyra cephalonica Stanton
Herculia psammoxantha
Hypsoorygia costalis (Fab.)
Paralispa gularis
Plodia interpunctella (Hübner)

Family - Tineidae - Clothes moths and allies
Monopis crocicapitella (Clemens)
Monopis monachella (Hübner)
Setamorpha insectella (Fab.)
Setamorpha rutella Zeller
Tinea cloacella Haworth
Tinea fuscipunctella Haworth
Tinea granella (L.)
Tinea nemapogin
Tinea pellionella (L.)
Tineola biselliella Himmel
Trichophaga tapetzella (L.)

Family - Tortricidae
Eulia voluitinana Wlk.

Families not identified
Cocoecia franciscana
Tortilia viatrix

Small tabby
Rice moth, wolf moth
Clover bagworm, gold fringe
Bean or rice moth
Indian meal moth
Insect moth
Tropical tobacco moth
Cork moth
Wolf moth, corn moth
Case-making clothes moth
Webbing clothes moth
Carpet moth, tapestry clothes moth, white-tip clothes moth

Tapestry moth, carpet moth
Order COLEOPTERA - Beetles

Family - Anobiidae - Furniture beetles; deathwatch beetles
   Catorama punctulatum Le Conte
   Catorama tabaci Guérin-Méneville
   Lasioderma serricorne (Fab.)  Cigarette beetle, towbug
   Sitodrepa panicea (L.)  Drugstore beetle
   (formerly Stegobium paniceum (L.) )

Family - Anthicidae - Anthicid beetles
   Anthicus floralis (L.)

Family - Bostrichidae - False powder post beetles
   Dinoderus minutus (Fab.)  Bamboo borer
   Dinoderus truncatus Stephens  Larger grain borer
   (formerly Stephanopachys truncatus (Horn) )
   Rhizopertha dominica (Fab.)  Lesser grain borer, Australian wheat weevil

Family - Cleridae - Checkered beetles
   Korynetes caeruleus
   Necrobia ruficollis (Fab.)
   Necrobia rufipes De Geer  Copra beetle, red-legged ham beetle
   Necrobia violacea (L.)

Family - Colydiidae - Cylindrical bark beetles
   Marmidius ovalis Beck
   Thaumaphrastus karanisensis Blaisdell

Family - Cryptophagidae - Silken fungus beetles
   Cryptophagus croceus Zimmermann
   Cryptophagus inscitus Casey
   Cryptophagus saginatus Sturm
   Henoticus californicus (Mannerheim)
   Pharaxonatha kirschi Reitter  Mexican grain beetle

Family - Cucujidae - Flat bark beetles
   Ahasverus advena (Waltl)  Foreign grain beetle
   Laemophloeus ferrugineus (Stephens) Rust-red grain beetle
   Laemophloeus minutus (Olivier)  Flat grain beetle
   Laemophloeus modestus Say
   Laemophloeus turcicus Grouvelle
Family - Curculionidae - Weevils

*Caulophilus latinasus* (Say)

*Cylas formicarius elegantulus* (Summers)

*Sitophilus granarius* (L.)

*Sitophilus oryzae* (L.)

Family - Dermentidae - Skin beetles

*Anthrenus scrophulariae* (L.)

*Anthrenus verbasci* (L.)

*Anthrenus vorax* Waterhouse

*Attagenus piceus* Olivier

*Dermestes ater* De Geer
(syn. *D. cadaverinus* (Fab.) = Incinerator beetle)

*Dermestes lardarius* (L.)

*Dermestes maculatus* De Geer
(syn. *D. vulpinus* (Fab.))

*Dermestes carnivorous* (Fab.)

*Thylodrias contractus* Motschulsky

*Trogoderma inclusum* Le Conte

*Trogoderma ornata* Say

*Trogoderma sternale* Jayne

*Trogoderma versicolor* Creutzer

*Trogoderma tarsale* Melsheimer

Family - Lathridiidae - Minute brown scavenger beetles

*Cartodera argus* Reitter

*Cartodera costulata* Reitter

*Cartodera filum* Aubé

*Cartodera ruficollis* Marsham

*Corticaria fenestralis* (L.)

*Corticaria pubescens* Cyllenhaal

Broad-nosed grain weevil

Sweet potato weevil

Granary weevil

Rice weevil, black weevil

Common carpet beetle

Varied carpet beetle, small cabinet beetle

Furniture carpet beetle

Black carpet beetle

Black larder beetle

Larder beetle

Hide beetle, skin beetle

Tissue paper beetle

Large cabinet beetle

Larger cabinet beetle, varied cabinet beetle

Larger cabinet beetle
*Enicmus minutus* (L.)
*Enicmus protensicollis* Mannerheim
*Enicmus suspectus* Fall
*Holoparameceus caularum* Aube
*Holoparameceus depressus* Curtis
*Holoparameceus singularis* Beck
*Melanophthalma americana* Mannerheim

Family - Lyctidae - Powder post beetles

*Lyctus brunneus* Stephens

Family - Mycetaeidae - Mycetaeid beetles

*Mycetaea hirta* (Marsham)

Family - Mycetophagidae - Hairy fungus beetles

*Litargus balteatus* Le Conte
*Mycetophagus bipustulatus* Melsheimer
*Typhaea stercorea* (L.)

Family - Mylabridae - Pea and bean weevils

*Acanthoscelides obtectus* (Say)
*Bruchus rufimanus* Boheman
*Bruchus pisorum* (L.)
*Callosobruchus maculatus* (Fab.)

*Mylabris chinensis* (L.)
*Mylabris pruininus* Horn
*Mylabris lentis*
*Mylabris prosopis* Le Conte
*Spermophagus pectoralis*
*Spermophagus subfasciatus*

Family - Nitidulidae - Sap-feeding beetles

*Carpophilus decipiens* Horn
*Carpophilus dimidiatus* (Fab.)
*Carpophilus hemipterus* (L.)
*Carpophilus nitens* Fall
*Carpophilus palipennis* (Say)

Old World powder post beetle

Hairy fungus beetle

Common bean weevil

Broad bean weevil

Pea weevil

Four-spotted bean weevil, Southern cowpea weevil

Cowpea weevil

Corn sap beetle

Dried fruit beetle
Meligethes aeneus (Fab.)  
Rape beetle
Stelidota geminata (Say)
Urophorus humeralis (Fab.)

Family - Ostomatidae - Grain and bark-gnawing beetles
Lophocateres pusillus (Klug)  
Siamese grain beetle
Tenebroides corticalis Melsheimer
Tenebroides nanus Melsheimer
Tenebroides mauritanicus (L.)  
Cadelle

Family - Platystomidae - Platystomid weevils
Araecerus fasciculatus (De Geer)  
Coffee bean weevil
Brachytarsus alternatus (Say)
Brachytarsus stricticus Boheman

Family - Ptinidae - Spider beetles
Gibbium psylloides (Czempinski)  
Hump beetle
Mezium americanum Laporte
Niptus hololeucus Faldermann
Ptinus bicinctus Sturm
Ptinus californicus Pic
Ptinus fur (L.)  
White-marked spider beetle
Ptinus sandolpheli Pic
Ptinus hirtellus Sturm
Ptinus latro (Fab.)
Ptinus raptor Stehr
Ptinus ocellus Brown
Ptinus villiger (Reitter)
Sphaerius gibboides (Boildieu)
Trigononotus globulus Solier

Family - Scolytidae - Engraver or bark beetles
Cocconotyles dactyliperda (Fab.)

Family - Silvanidae - Flat bark beetles
Cathartus advena (Waltl)  
Foreign grain beetle
(Formerly Ahasverus advena (Waltl))
Cathartus quadricollis (Guérin-Méneville)  
Square-necked grain beetle
Nausibius clavicornis (Kugelmann)
Oryzaephilus bicornis (Erichson)
Oryzaephilus roseipil
Oryzaephilus mercator Fauvel
Oryzaephilus (=Silvanus) surinamensis (L)

Saw-toothed grain beetle, corn silvanis

Family - Staphylinidae - Short-winged scavenger beetles
Atheta coriara Kraatz
Rove beetles

Family - Tenebrionidae - Darkling beetles
Alphanotus destructor (Uyttenberg)
False black flour beetle
Alphanotus parallelus Casey
Lesser mealworm
Alphitobius diaperinus (Panzer)
Black fungus beetle, grain mold beetle
Alphitobius niceus (Olivier)
Two-banded fungus beetle

Alphitophagus bifasciatus (Say)
Churchyard beetle

Apsena rufipes Eschscholtz
Blapa mucronata Latreille
Blapstinus dilatatus Le Conte
Blapstinus rufipes Casey
Cnemplatia sericea Horn
Cynaeus angustus Le Conte
Gnathocerus constrictus (Fab.)
Churchyard beetle
Gnathocerus maxillosus (Fab.)
Blatheticus oryzae Waterhouse
Palorus ratzeburgi (Wissmann)
Slender-horned flour beetle
Palorus subdepressus (Wollaston)
Long-headed flour beetle
Platydema ruficorne Sturm
Small-eyed flour beetle
Depressed flour beetle
Sitophagus hololeptoides (Castelnau)
Tenebrio molitor (L.)
Tenebrio obscurus (Fab.)
Tenebrio pictipes Herbst
Tribolium castaneum Herbst
(formerly known as T. ferrugineum (Mulsant))
Tribolium confusum Jacq. Duval
Tribolium madens Charpentier

Order HYMENOPTERA - Wasps, ants, bees, and allies
Family - Formicidae - Ants
Atta texana Buckley
Camponotus herculaeus pennsylvanicus De Geer
Formica cinera
Iridomyrmex analis
Iridomyrmex humilus Mayr
Liometopum apiculatum occidentale
Monomorium destructor
Monomorium pharaonis (L.)
Solenopsis molesta Say
Solenopsis xyloni MacCook
Solenopsis xyloni maniosa
Tapinoma sessile (Say)

Order DIPTERA - Flies
Family - Anthomyiidae
Fannia pusio
Fannia scalaris (Fab.)

Yellow mealworm
Dark mealworm; dusky mealworm
Rust-red flour beetle
Confused flour beetle
Black flour beetle
Texas leaf-cutting ant
Black carpenter ant
Argentine ant
California velvety tree ant
Pharaoh's ant, yellow or red house ant
Tiny thief ant
Southern fire ant, MacCook's fire ant
California fire ant
Odorous house ant
Latrine fly
Family - Drosophilidae - Pomice or vinegar flies

*Drosophila buscki*
*Drosophila funebris*
*Drosophila immigrans*
*Drosophila melanogaster*
*Drosophila repleta*

Family - Calliphoridae - Blow flies

*Calliphora erythrocephala* Meigen (Blue bottle fly)

Family - Muscidae - House and stable flies and their allies

*Lucilia caesar* (L.) (Green bottle fly)
*Lucilia aerica* Meigen (False stable fly)
*Muscina stabulans* (Black blow fly)
*Phormia regina* (House fly)
*Musca domestica* (L.) (Cheese or ham skipper)

Family - Piophilidae

*Piophila casei* (L.)

Family - Sarcophagidae - Flesh flies

*Sarcophaga* sp. (Gray flesh flies)
B. Stored-Food Product Coleoptera
Arranged Phylogenetically According to Superfamilies and Families

Suborder POLYPHAGA

Superfamily STAPHYLINOIDEA
Family - Staphylinidae

Superfamily CUCUJOIDEA
Family - Cryptophagidae
  " Silvanidae
  " Cucujidae
  " Nitidulidae
  " Anthicidae
  " Colydiidae
  " Mycetophagidae
  " Tenebrionidae
  " Mycetaeidae
  " Lathrididae

Superfamily CLEROIDEA
Family - Dermestidae
  " Ostomatidae
  " Cleridae

Superfamily BOSTRICHIOIDEA
Family - Ptilidae
  " Anobiidae
  " Bostrichidae
  " Lycidae

Superfamily CHRYSEMBOLIOIDEA
Family - Mylabridae

Superfamily PLATYSTOMOIDEA
Family - Platystomidae

Superfamily CURCURIONIOIDEA
Family - Curculionidae
  " Scolytidae
C. Plates and Figures
Fig. 112.—Section through the thin-walled type of sensillum (probably olfactory) on antenna of *Rhodnius* (cf. Fig. 115, b) (after WIGGLESWORTH and GILLET)

a, trichogen or glandular cell; b, bundle of terminal filaments from the sense cells; c, fusiform mass of sense cells numbering about 15.

Figure 1

Fig. 115.—Surface view of part of an antennal segment in *Rhodnius* (after WIGGLESWORTH and GILLET)

a, tactile spine; b, thin-walled sensillae, probably olfactory (cf. Fig. 120); c, fine thick-walled sensilla, perhaps temperature receptor (cf. Fig. 137); d, short sensillae showing the same structure as c.

Figure 2

Figure 3

Detail of olfactory pit showing sensory rods, each supplied by a single sense cell.

(from WIGGLESWORTH after Idebermann)
Figure 4

**Fig. 134.**—Longitudinal section of tip of labial palp of *Pieris rapae* showing pit containing olfactory rods (*after Hof*)

- a, covering scales;
- b, pit;
- c, sensory rods;
- d, nerve.

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**Fig. 135.**—Sensilla on antenna of *Apis* (*after Hof*)

- a, placoid sensillum;
- b, thin-walled trichoid sensillum;
- c, distal sheath cell;
- d, basal sheath cell;
- e, sensory rodlets;
- f, terminal filament;
- g, sense cells.

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**Figure 5**
Figure 6

Left - typical Cucujid larvae. Note the flattered bodies, with the gut visible externally. The anterior ends are at the left. The larva on the bottom is lying ventral side uppermost. The photograph to the right is an enlargement of the ventral head view. Note the hypopharynx, palps, and relatively short larval antennae. These larvae are very closely related to package-infesting Cucujids.

(original)
Figure 7

Top - yellow mealworms, Tenebrio molitor L., approximately natural size. Bottom - enlarged view of yellow mealworms in flour medium. Note the legs which serve to distinguish them from the wireworms.

(original)
Figure 18

Yellow Meal Worm, *Tenebrio molitor*. a, larva; b, pupa; c, adult female; d, egg with case; e, antenna. From Chittenden.

Figure 19

Pupa of dark mealworm, *Tenebrio obscurus* F., ventral view. Compare with Fig. 18, b. The two prominent structures at the tip of the mouth are palps.
Figure 10

Same as Fig. 17 - lateral view. The pin was used for mounting. (original)

Figure 11

Adult of Tenebrio molitor L. Compare with Fig. 38, c. (from Smallman)
Figure 12

Larva of the furniture carpet beetle, *Anthrenus vorax* Waterhouse. Ventral view. Note the hairs characteristic of Dermestid larvae. The larder beetle larva closely resembles this one. Compare Fig. 14, b.

(original)

Figure 13

Adult of *Anthrenus vorax* Waterhouse. The adult is innocuous in that it does not attack stored foods or packages. It frequently is found on flowers just outside the house. Left - ventral view, showing characteristic Dermestid antennae. Right - dorsal view, greatly enlarged, showing scales.

(original)
Common Carpet Beetle (*Anthrenus seepulare*), a, larva, dorsal view; b, pupa within larval skin; c, pupa, ventral view; d, adult. From Riley, U.S.D.A.

*Figure 14*


*Figure 15*
102 - Hide beetle, *Dermestes maculatus* De Geer
103 - Dried-fruit beetle, *Carpophilus hemipterus* (L.)
104a - Saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.). The family *Silvanidae* is the more recent and correct grouping.

(from Swain - The Insect Guide)
Silphids (beetles of the family Silphidae, the burying beetles. Left - the sexton beetle, Macrophorus marginatus. Right - the carrion beetle, Silpha novaboracensis. These are not essentially stored-food product insects, although they might be considered as such. (from Swain - The Insect Guide)

Figure 19

Dorsal view of the broad-horned flour beetle, Gnathocerus cornutus (F.). Left - whole body. Right - head region, greatly enlarged, showing the powerful mandibles which give this insect its common name. (original)
Figure 26

Saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.). Ventral view, greatly enlarged. The arrow indicates the serrations or saw-teeth on one side. Compare with Fig. 16 (104a) (original)

Figure 27

Cigarette Beetle (*Lasioderma serricorne*). a, larva; b, pupa; c, adult, dorsal view; d, adult, lateral view; e, antenna. From Chatrandon.
Drugstore Beetle (*Silodriza panicea*). *a*, larva; *b*, pupa; *c*, adult, dorsal view; *d*, adult, lateral view; *e*, antenna. (From Chittenden.)

**Figure 22**

Flat Grain Beetle (*Larophagus pumilus*). Note the long antennae. This beetle is one of the smallest found in stored grain. (From U.S.D.A. Farmers Bull. 1260.)

**Figure 23**
Figure 24

The rust-red grain beetle, *Laemophloeus ferrugineus* (Stephens). (from Smallman)

Figure 25

*Alphanotus destructor*, adults and larva, and a carton, showing the damage wrought by this insect. (from Verdcourt)
Figure 26

Rice weevil, *Sitophilus oryzae* (L.). Note the circular pits and the markings on the elytra. This photograph is enlarged to the same scale as Fig. 27. It will be noticed that the rice weevil is slightly smaller.

(from Forbes - Illinois State Natural History Survey)

Figure 27

Granary weevil, *Sitophilus granarius* (L.). Note the longitudinal pits and the absence of markings on the elytra. This insect is slightly larger than the rice weevil.

(from Forbes - Illinois State Natural History Survey)
Confused Flour Beetle (*Tribolium confusum*).  a. beetle; b. larva; c. pupa; all - times natural size; d. lateral lobe of abdomen of pupa; e. head of beetle, showing antenna; f. (*Tribolium ferrugineum*) - all greatly enlarged. (From Chittenden.)

**Figure 28**

The confused flour beetle, *Tribolium confusum* Jacq. Duval. Left - larva in natural flour habitat, showing a molted "skin" at the extreme left. Right - adults in natural flour habitat - left, dorsal, and right, ventral views. (original)
Figure 30

Fig. 528. The cadelle, *Tenebroides mauritanicus* (Linneé), about four times natural size. A. egg; B. mature larva, dorsal view, showing characteristic spots on thoracic segments, and the various rigid hooks on tip of abdomen; C. pupa, ventral view; D. adult, showing the strong constriction between prothorax and mesothorax; E. last three abdominal segments of larva in side view, showing terminal hooks and spiracles. (Drawn from Nature.)

Figure 31

Living adults of the cadelle, *Tenebroides mauritanicus* (L.). Left - dorsal view. Right - ventral view. Compare with Fig. 30. (original)
Various views of an Elaterid beetle. Note the flat body. This insect was found in a cell under the bark of a fallen rotting tree. Probably Elateridae are closely related to package-infesting insects, which are thought to come from similar environments.

Figure 33

This is one of the test insects called for in the TAPPI Tentative Standard T 473 m-47.
Figure 34

Common termite, Reticulotermes flavipes.
(from Swain - The Insect Guide)

Figure 35

17 - Embiid - Oligotoma saundersii
18 - Psocid - Psocus confiratermus
19 - Common booklouse - Liposcelis divinatorius
(from Swain - The Insect Guide)
Figure 36

European earwig, *Forficula auricularia*
(from Swain - The Insect Guide)

Figure 37

A Gryllid (cricket), one of the few Orthoptera that are food pests. Species unidentified. (original)
Figure 38

A large black ant, probably a carpenter ant. Found in the field under bark. Lateral and ventral views. Note the palps in the mouth region (enlarged view) (original)
Figure 39

Silverfish (*Leptisma saccharina*). (From Ill. Agri. Exp. Stat., circ. 257.)

Figure 40

*Thermobia domestica* is the firebrat, in the same order (*Thysanura*) as the silverfish shown just above. (Fringes and Fringes)
A Common Mite (*Tyroglyphus* sp.)

**Figure 41**

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**Figure 42**
Figure 43

Figure 44
Case making Clothes Moth (*Tinea peliana*) Upper, adult moth, x40; right, larva, x6; left, larva partially concealed in the case, x400. Observe the dark spots on the buff-colored fore wings of the adult of the case-making clothes moth from that of the webbing clothes moth, the wings of which are uniformly buff-colored. (From U.S.D.A. Farmers Bull 1655.)

Figure 45

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Fig. 59: -- 10X cloth will remove all eggs of flour infesting insects. Left to right: Eggs of broad-billed flour beetle, odalla, Mediterranean flour moth, and confused flour beetle on 10X cloth.

(After Wagner and Cotton)

Figure 45
Fig. 60: Eggs of flour infesting insects vary in size and shape. Eggs of the important mill insects are shown resting on bolting cloth just fine enough to remove them from flour. Left to right, top to bottom—Eggs of the flat grain beetle on 10XZ cloth; Cadelle eggs on 7XX cloth; Confused flour beetle eggs on 6XX cloth; Indian meal moth eggs on 7XX cloth; Eggs of broad-horned flour beetle on 6XX cloth; and Eggs of Mediterranean flour moth on 6XZ cloth. 
(After Wagner and Cotton)

Figure 47
Fig. 61: -- Larvae of flour infesting insects are often small enough to wriggle through cloth that will remove the eggs they hatched from. Day-old larvae of a number of mill insects are shown resting on bolting cloth just fine enough to remove them from flour. (After Wagner and Cotton)
Figure 49

Excreta of stored grain insects.
(from Cotton)
-all shown to same scale
Figure 50

A cake flour package showing typical tight-wrap construction. Note the possible point of entry for insects at the near corner.

Figure 51

A package for dehydrated soup mix constructed with glued top flaps. Note the inviting entry path for insects.
Figure 52

A metal can for dehydrated materials, such as the powdered ice cream mix in this can, represents the ultimate in protection against insect infestation. It naturally has other advantages also.

(original)

Figure 53

Holes bored in the lead sheathing of aerial cables by the California lead cable borer (*Scobica declivis* Lec.), from various localities in California.

(from U.S.D.A. Dep't. Bul. 1107)
Figure 1

Fig. 1. The can-arena method was so satisfactory that, with slight modifications, it was used in all the principal experiments.

Fig. 2. The mason jar-top arena is a modification of the can-arena method shown in accompanying figure 1.

Figure 54

Test units used by Chamberlain and Hoskins. In the unit at the right the Petri dish below the test sheet is just barely visible by its seal.

(from Chamberlain and Hoskins)

Figure 55

Crystallizing dish test unit used in this thesis. The food bait at the bottom is flour. Note the sponge in the top chamber with the insects.

(original)
Figure 56

Shell beans attacked by bean weevils (*Acanthoscelides obtectus* (Say)). Note the insects still in the holes. (original)

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Figure 57

Cadelles eating their way through corn kernels. An intact kernel is shown for comparison. (original)
Figure 58

Examples of penetrations in the crystallizing dish test. Top - crinkled parchment through which dark mealworms (larvae) have penetrated. Three holes were cut through this large test disc. Middle - (toilet) tissue penetrated by cadelle adults. Note slit under Scotch tape which one cadelle made. Bottom - portion of toweling paper through which cadelles penetrated.

(original)
Figure 59

Left - polyethylene bag made from seamless tubing and heat-sealed at both ends. This type bag or packet was used in later testing. In some tests insects were placed inside with a damp sponge, and the food bait was on the outside. In others the situation was reversed. Note the chewed-off corner caused by mealworms. Right - enlarged view of chewed-off corner. (original)

Figure 60

A bag made for the same tests as described in Fig. 59, but made from polyethylene-coated kraft paper. This coating was only on one side. This paper is heat-sealable on the coated side only, but a satisfactory test bag was made as shown. (original)
Mason jar assembly used in later testing. Left - entire unit as sold. The circular disc is not used in testing. Right - view showing how test sheet is mounted between jar and screw closure. The excess sheet can then be trimmed off.

(Original)

Figure 62

Left - the entire Mason jar assembly as used in testing. The food bait is placed in the Petri dish and the insects are placed inside the jars along with a wet sponge. Right - results of infestation or penetration by mealworms. The sheet on the left is onion skin paper, while the sheet on the right is toilet tissue. (original)
Diagram showing hypognathous type of head structure.

**FIGURE 63**

Diagram showing prognathous type of head structure.

From Snodgrass, R.E., *Annual Report Smithsonian Institution*, 1931

**FIGURE 64**
Diagrams showing the general structure of an insect's head and the relations of the mouth parts to the cranium.

From Snodgrass, R.E., Annual Report Smithsonian Institution, 1931

Figure 65
Diagram of the structure and musculature of the first maxilla of an insect.

From Snodgrass, R.E., Smithsonian Institute Miscellaneous Collection, 1943

Figure 66
Head of *Tinga pollesontella* Staint. showing long and filiform maxillary palpi.

**Figure 67**

Head of *Tinga bisselliella* (Hümmel) showing short and inconspicuous maxillary palpi.


**Figure 68**
Diagram of typical pterygote mandibles

**Figure 69**

Diagram of typical pterygote mandibles

*from Snodgrass, R.E., Annual Report, Smithsonian Institute 1931*

**Figure 70**
Diagram of the structure and mechanism of an insect mandible that serves as a biting and chewing jaw, movable in a transverse plane on the indicated axis by an abductor and an adductor muscle.

**Figure 71** from Snodgrass, R.E., Annual Report Smithsonian Institution, 1931

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1. *Tribolium* spp. 84.65%
2. *Laemophloeus* spp. 7.95%
3. *Tenebroides mauritianus* L. 3.16%
4. *Rhizopertha dominica* Fab. 1.78%
5. *Sitaphilus* spp. 0.98%
6. *Latheticus oryzae* Waterhouse 0.76%
7. All others 0.72%

Percentages of different species of insects taken in mill streams of flour mills.

**Figure 72**

*From Good, N.E., Journ. Kansas Ent. Soc., 1937*
BIOTIC CONSTANTS
FOR THE
DURATION OF VARIOUS STAGES
IN THE LIFE OF
TRIBOLIUM CONFUSUM
AT
75% RELATIVE HUMIDITY

(afer Chapman and Baird - 1934)

Note - at 17°C, the larvae
died before pupating.

TIME IN DAYS

TEMPERATURE, °C.

Figure 73
MOISTURE EQUILIBRIA
OF
TYPICAL STORED FOOD PRODUCTS

% MOISTURE

% RELATIVE HUMIDITY

FIGURE 74

\[ \text{Data Sources:}
\begin{align*}
\text{Hellman and Melvin 1948} \\
\text{Brockington, Dorin and Howerton 1949} \\
\text{Karen and Adams 1949} \\
\text{Landrock and Proctor 1950} \\
\text{Elder 1949} \\
\text{Bailey 1920}
\end{align*} \]
INSECT RESISTANCE OF PACKAGES, PAPER, AND PAPERBOARD

This method is for testing the resistance of packages, paper, or paperboard to insects. The larvae of the cadelle (Tenebroides mauritianus L.) and the adults of the lesser grain borer (Rhyzopertha dominica F.) are selected as test insects. Both insects are widespread and both, especially the cadelle larvae, have unusual ability in penetrating packaging materials.

Apparatus and Materials

1. Test Insects. A hundred adult insects of either species, preferably more of the cadelle, which breed rather slowly, will start a small colony. The lesser grain borer is readily obtained in stores of grain in the South and the cadelle in quantity in most parts of the country from bins of farm-stored wheat. A commercial source of supply for the insects is California Insectaries, Inc., 1612 W. Glendale Blvd., Glendale, California. If proper care is given the colonies, one lot will produce an inexhaustible supply. The lesser grain borer can be reared in wheat which has a moisture content of about 12%, in any type of available container. The cadelle is not easily reared in small containers because of its cannibalistic habits, but it may be successfully reared in a large metal can of 15-gallons or more capacity filled with rolled barley or wheat, the bottom few inches of the grain being dampened to make a wet mash. A temperature of about 27 to 30°C. (80 to 86°F.) and fairly humid conditions (65 to 90% R. H.) are favorable to and will speed the development of both insects.

2. Test Chamber (for Method A). A screened top metal tank 3 by 2 by 1 feet, or other convenient size, containing a 2-inch deep layer of infested wheat.

If about 200 lesser grain borer adults are added, the chamber will be ready for immediate use and the colony will last indefinitely, provided that the grain is renewed occasionally.

About 60 to 100 full grown cadelle larvae added from the main breeding can will make the chamber ready for use. The larvae will require renewal from time to time as they are transformed to adults, die, or are removed from the tank with the test specimens.

The absence of insects of either variety crawling over the test specimens indicates the need for adding more insects.

3. Specimen Holders (for Method A). A number of slip-cover seamless drawn ointment or pill metal boxes with a circular hole approximately 1.5 inches in diameter cut in each lid. A supply of waterproof adhesive (Duco or similar) is also needed.

4. Specimen Holders (for Method B). A number of pairs of shallow glass crystallizing dishes about 2½ inches (75 mm.) in diameter and ½ inch deep. A quantity of ⅛-inch wide transparent adhesive tape for joining them together mouth to mouth.

5. Larvae Bait. A supply of whole wheat flour or shorts or middlings used as “bait” for the larvae.


7. Cabinet or Room, maintained at 28.5 ± 1.5°C. (83 ± 3°F.) and 75 ± 10% relative humidity. For Method B, a desiccator containing a saturated solution of C.P. sodium chloride with excess crystals may be used, placed in a cabinet with temperature controlled at 28.5 ± 1.5°C.

Test Specimen

Prepare at least three and preferably five specimens from each sample to be tested, taken in such a way as to be representative of it.

For Method A: The preferred test specimen is the completed package for which the material is to be used, filled with the whole wheat flour or shorts. For testing individual sheets, cut disks of such a size as to cover the opening in the lid of the sample holder with an overlap of about ¼ inch around the edge. Fold each specimen along the center (preferably before cutting into a disk) parallel to the machine direction, and if two sided, with the normal outer surface on the outside of the crease; subject the crease to a load of 6 pounds per inch (1 kg. per cm.) for 10 to 15 seconds; then similarly fold and press in the cross direction (the outer surface again being outside the crease), forming a crossed crease in the center of the specimen.

For Method B: Crease the test specimen as described and cut into disks having approximately the outside diameter of the test dishes.
**METHOD A.**

If the sample is not in the form of a finished package, prepare test assemblies as follows: Remove the lid from each tin box and cement the creased specimen over the hole on the inside of the lid, applying the adhesive all around the specimen, taking care not to smear the exposed surface, with the outside surface of the specimen facing the outside of the lid. Allow all the solvent to dry from the adhesive. Add sufficient bait to cover the bottom of the tin box to a depth of \(\frac{1}{8}\) to \(\frac{1}{4}\) inch and put on the cover with the attached specimen. Prepare also the same number of test assemblies using a second sample with which the first is to be compared or if not, or in addition, assemblies using the standard comparison paper. It is preferable to include the standard material with each test or at frequent intervals, to ensure that overall conditions do not change significantly. Place the boxes, lids down, or the finished packages, on the layer of infested wheat in the tank and keep the tank in a room maintained at 28.5 ± 1.5°C and 75 ± 10% relative humidity. Because the insects prefer the milled cereal food in the tin boxes, they will cut through the material being tested unless it is sufficiently repellent to resist penetration. Examine the boxes daily and record the number of days it takes for an insect to cut its way through.

**METHOD B.**

To one of a pair of flat glass dishes, add enough bait which has been conditioned at 28.5 ± 1.5°C and 75% ± 10% relative humidity to cover the bottom \(\frac{1}{8}\) to \(\frac{1}{4}\) inch deep and, with a little glue, paste a specimen over the top of the dish with the outside surface of the specimen facing outside. Place only one well grown cadelle larva (about \(\frac{3}{4}\) inch long) or two or three lesser grain borer adults in the second dish or on the specimen and cover the specimen with the inverted second dish, using a strip of adhesive tape to fasten the two dishes together. Prepare similar assemblies with standard or other comparative specimens. Keep the assemblies at 28.5°C, preferably in an atmosphere at 75% R.H.

The insects will attempt to cut through the specimen to reach the food below. Record the number of days required for the insects to penetrate the specimens. If necessary, replace any insects which die. Normally, however, they will live quite awhile without food. Complete visibility with this test assembly makes examination easy and rapid.

**Report**

Report the result in terms of the average number of days elapsed before complete penetration of the specimen occurs, and state the method (A or B), the kind of insect used, the average time taken to penetrate the standard or a comparative specimen under the same conditions, and a complete description of the sample material and of the standard material used for comparison.
XIII. BIBLIOGRAPHY

Abbott, C. E.
1936. The physiology of insect senses.

Back, E. A. and R. T. Cotton
1926. Biology of the saw-toothed grain beetle,
Oryzaephilus surinamensis Linne.

1940. Stored-grain pests.
U. S. Department of Agriculture Farmers' Bulletin
No. 1260 (Superintendent of Documents, Washington,
D. C. - 10 cents)

Bailey, C. H.
1920. The hygroscopic moisture of flour when exposed to
atmospheres of different relative humidity.
Journal of Industrial and Engineering Chemistry, 12:
1102-1104.

Blake, C. H.
1943. Insects and other animals of interest to the
Quartermaster Corps.
National Defense Research Committee of the Office of
Scientific Research and Development. (O.S.R.D. No. 2091)

1950. Personal communication.

Blatchley, W. S. and C. W. Leng
1916. Rhyncophora or weevils of north eastern America.

Brindley, T. A.
1930. The growth and development of Ephemia kuhniella
Zeller and Tribolium confusum Duval under controlled
conditions of temperature and humidity.
Annals of the Entomological Society of America, 23:
741-757.

Brookington, S. F., Dorin, H. C., and H. K. Howerton
1949. Hygroscopic equilibria of whole kernel corn.

Brown, W. E. and A. E. Higgins
1942. The control of insects infesting dried fruits. 22 pp.
His Majesty's Stationery Office, London
(price 6 d net)
Brues, C. T.  
1946. *Insect Dietary* - an account of the food habits of insects. 

Burton, L. V.  
1949. *Insect-free packaging (Infestation prevention in containers).* 
An address before the 18th Packaging Conference of the American Management Association, Atlantic City, New Jersey, May 11, 1949. ( Mimeographed)

Chamberlain, W. F. and W. M. Hoskins  

Chamberlain, W. J.  
1939. *The bark and timber beetles of North America (north of Mexico).* 
*Oregon State College Cooperative Association, Corvallis.*

Chapman, R. N.  
1926. *Inhibiting the process of metamorphosis in the confused flour beetle (Tribolium confusum).* 
*Journal of Experimental Zoology, 45:* 293.


Chapman, R. N. and L. Baird  
*Journal of Experimental Zoology, 68:* 293-304.

Coleman, D. A. and H. C. Fellows  
1925. *Hygroscopic moisture of cereals, grains and flaxseed exposed to atmospheres of different relative humidity.* 
*Cereal Chemistry, 2:* 275-287.

Corbet, A. S. and W. H. T. Tams  
1943. *Key for the identification of the Lepidoptera infesting stored food products.* 
*Proceedings of the Zoological Society, Series B, 113:* 55-148. (In reprint form, bound with another reprint in a volume published by the Ministry of Food called "Insect Pests of Food" and available at His Majesty's Stationery Office at a cost of 5 s 0 d. net - S.O. Code No. 70-445.)
Cotton, R. T.
1941. Insect pests of stored grain and grain products. Burgess Publishing Company, Minneapolis.


Cotton, R. T., Frankenfield, J. C. and G. A. Dean

Dethier, V. G.

Edwards, J. G.
1949. The Coleoptera or beetles east of the great plains. Ann Arbor, Michigan. Lithoprinted by the author, who lives at 392 Prairie Ave., Wilmington, Ohio.


Frings, H.

Frings, H. and M. Frings
Glaser, R. W.
1927. Evidence in support of the olfactory function of the antennae of insects.

Good, N. E.
1937. Insects found in the milling streams of flour mills in the southwestern milling area.

Hellman, N. N. and E. H. Helvin
1948. Water sorption by corn starch as influenced by preparatory procedures and storage time.
Cereal Chemistry, 25 (2): 146-150.

Hinton, H. E.
British Museum (Natural History), London.

Karon, M. L. and M. A. Adams
1949. Hygroscopic equilibrium of rice and rice fractions.

Landrock, A. H. and B. E. Proctor
As yet unpublished data.

Leng, C. W.
1925-32. Supplements 2 and 3 with A. J. Hutchler.
1939. Supplement 4 by R. E. Blackwelder.
All published by John D. Sherman, Jr., Mount Vernon, N.Y.
Linsley, E. G.
1944. Protection of dried packaged foodstuffs from insect damage.

McIndoo, N. E.
1914. The olfactory sense of insects.
Smithsonian Miscellaneous Collections, 63 (9): 63 pp.
Smithsonian Institution, Washington - Publication No. 2315.

1926. An insect olfactometer.
Journal of Economic Entomology, 19 (3): 545-571.

1928. Responses of insects to smell and taste and their values in control.

Metcalf, C. L. and W. P. Flint

Michelbacher, A. E.
1947. Insects ... and how to control them; more data from the Berkeley study of package pests and the storage conditions which favor growth.

Minnich, D. E.
1929. The chemical sense of insects.
Quarterly Review of Biology, 4: 100-112.

Modern Packaging Encyclopedia (anonymous)
Packaging Catalog Corporation, New York.

Park, T.
Quarterly Review of Biology, 2: 36-54.

Proctor, E. E. and J. C. Sluder
1942-43. Resistance of packaging materials to insect penetration.
Annual Report on QM Contract, Food Technology Laboratories, Massachusetts Institute of Technology,
Section XI, pp. 208-211.

1943-44. Testing of packaging materials for properties of resistance to penetration of insects.
Annual Report on QM Contract, Food Technology Laboratories, Massachusetts Institute of Technology.
Section XI, pp. 263-274.
(Note - These reports were written by T. H. Derby, Jr., who also carried out the work.)

Rabaud, E. (Translated from the French by I. H. Myers)
1928. How animals find their way about - a study of distant orientation and place recognition.
International Library of Psychology, Philosophy, and Scientific Method.

Robinson, V. E.
1928. Response and adaptation of insects to external stimuli.

1930. The mouthparts of the larval and adult stages of *Dermestes vulpinus*.

Rosoff, H. D.
1943. The evaluation of food packaging materials from the standpoint of protection against insects.
An S. B. thesis in the Department of Biology and Biological Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

Ross, H. H.

Roth, L. M. and E. R. Willis
1948. The oviposition of *Dermestes ater* De Geer, with notes on bionomics and rearing technique.
Office of the Quartermaster General, Military Planning Division, Research and Development Branch, General Laboratories, Philadelphia Quartermaster Depot.
Smallman, B. N.
1945. Applied entomology in the cereal industries.

Snodgrass, R. E.
1931. Evolution of the insect head and the organs of feeding.
Superintendent of Documents, Washington, D. C.

1944. The feeding apparatus of biting and sucking insects affecting man and animals.
Smithsonian Miscellaneous Collections, 104 (7): 113 pp. (Publication 3773).
Smithsonian Institution, Washington, D. C.

Standen, A.
1943. Insect invaders.
Houghton, Mifflin Company, Boston.

Swain, R. B.

Sweetman, H. C. and A. I. Bourne
1944. The protective value of asphalt laminated papers against certain insects.

1947. Insect resistance of packages, paper, and paperboard. (T 473 m-47) - This is a Tentative T.A.P.P.I. Standard.

Ting, P. C.
1936. The mouthparts of the Coleopterous group Rhynchophora.
Microentomology, 1: Contribution No. 3, 93-114.
(Obtainable from the Director, Natural History Museum, Stanford University, for 35 cents).
1948.
Chemical Engineering, 55 (9): 179.

Valentine, J. M.
1931. The olfactory sense of the adult mealworm beetle Tenebrio molitor Linn.
Journal of Experimental Zoology, 58: 165-220.

Verdcourt, B.
1947. Insecticidal barriers.

Wigglesworth, V. B.
1939. The Principles of Insect Physiology.
XIV. ABSTRACT

This thesis was written as an attempt to provide the food packaging technologist with as much background as possible to enable him to understand the biological principles involved in insect infestations of food packages. Considerable factual information on most insects likely to be encountered as food pests is included as a reference source for those who are concerned with controlling these insects. A large number of figures have been included in order that the beginner in this field will not need to search for references showing illustrations of points made in the text. Most of these figures are original.

According to the most authentic figures, there are about 904 insect species attacking stored foods throughout the world. Of these, there are 542 Coleoptera (beetles) and 175 Lepidoptera (moths and butterflies). The remaining 187 are represented by a large number of lesser orders. Because of their obvious importance in any consideration of stored-food product pests, the Coleoptera have been stressed in this thesis.

A systematic list of insects and other arthropods infesting foods and food products in the United States has been provided. This list comprises 227 species and is arranged in zoological order down to families and species. The full scientific name is given and, where known, the common name or names. A careful study of this list will
show the zoological relationship between many of the common food insect pests. This knowledge may be of some help in determining the best methods of control.

As a further aid in understanding relationships between different groups of beetles, a chart has been prepared showing stored-food product Coleoptera arranged phylogenetically according to superfamilies and families.

A chart showing the known numbers of insect species of various orders attacking 21 types of food has been drawn up. Grains and other miscellaneous seed have the largest representation on this chart. Dried fruits of all types are also well-represented.

The section on olfaction and taste goes into considerable detail regarding these sensory functions and the structures used in receiving their stimuli. The chief organs concerned in olfaction are undoubtedly the antennae, although olfactory structures are also found on the palps and other regions of the body. The gustatory senses are known to be present in the palps and, in some cases, in the feet. A detailed description of all sensory structure types is presented for reference.

A section on food procurement follows the section on olfaction and taste. It is pointed out that the instinct to secure food is one of the primary instincts in insects, as in other creatures. Insects may be divided into several categories according to their dietary habits. There are
polyphagous insects, which are indiscriminate in their food choice. In the non-polyphagous insects there are phytophagous, carnivorous, saprophagous, and parasitic insects. This thesis is primarily concerned with the polyphagous insects and, in the non-polyphagous group, the phytophagous (especially mycetophagous) and the saprophagous insects.

Only insects with mandibulate mouthparts are capable of chewing their way through packaging materials. Although some mention is made of other types of mouthparts, naturally stress is laid upon mandibulate mouthparts in this thesis. Mention is also made of the very specialized type of chewing mouthparts found in the weevils (Rhyncophora).

The relationship of insects to packages containing foods is covered in some detail. It has been suggested that the insects now causing man so much trouble by infesting his foods originally were found in the nests and bedding places of animals and birds, or about the nests of other insects. Other insects may have originally fed on naturally distributed dried seeds. When man began to store these seeds, these insects naturally were very well-off.

Stored-food product insects are very ancient. One of our most common species has been found in a jar containing grain in a Pharaonic tomb in about 2,500 B.C.

Most stored-food product insects developed in the warmer parts of the world, and for this reason they usually have no
hibernation period. They are naturally poorly adapted to low temperatures, which factor is to be considered in their control. Life cycles are as short as 4-6 weeks. In general, they prefer foods with moisture contents of about 10-17%.

Insects found entering food packages may be classified as primary and secondary invaders. The former are capable of working their way into the package on their own initiative, usually by attacking some part of the package construction. The latter, on the other hand, take advantage of the efforts of the primary invaders and follow their paths.

Some insects may be found in food packages which were already there as the package was sealed. Methods of keeping out these insects are not treated in this thesis.

Some consideration is given to the various aspects of package construction affecting the entry of insect pests. The small size of early larvae of some forms is stressed with relation to the possibility of their entering food containers through minute openings.

The various types of tests used in measuring the resistivity of packaging materials to insects are described in some detail. The relative efficacy of the test insects used is discussed.

In the experimental portion of this thesis, work was carried out with several species, including mealworms, cadelle adults, and confused flour beetles. Test materials
included Pliofilm, polyethylene, cellophane, saran, cellulose acetate, parchment, glassine, laminates, tissue paper, toweling paper, and polyethylene-coated kraft paper. At first a crystallizing dish technique was used, with the addition of a wet sponge to provide moisture. In later work, experiments were carried out with Mason jars and with sealed bags.

It was found that Tribolium spp., even in the larval form, were incapable of penetrating the simplest continuous barriers. These are undoubtedly solely secondary invaders, although they are nonetheless important. Mealworms were excellent penetrators. On the other hand, cadelle adults were found to be good, but not excellent penetrators.

Tissue paper was regarded as a criterion as to whether or not an insect had any penetrating powers. Insects not penetrating tissue paper were not tested with any other materials.

In general, the insects were able to penetrate the bags more easily than the tautly drawn test sheets used in the crystallizing dish and Mason jar techniques.

During the test, no attempt was made to control temperature. The test units were exposed to laboratory light during the day.