AN INVESTIGATION OF THE EFFECTS OF MILLING FRACTIONS OF BREAD WHEAT ON THE BIOLOGY OF TWO CUCUJIDS *Cryptolestes turcicus* (GROUV.) AND *Cryptolestes ferrugineus* (STEPH.)

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ABSTRACT

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AN INVESTIGATION OF THE EFFECTS OF MILLING FRACTIONS OF BREAD WHEAT ON THE BIOLOGY OF TWO CUCUJIDS *Cryptolestes turcicus* (GROUV.) AND *Cryptolestes ferrugineus* (STEPH.)

The purpose of this investigation was to learn something of the effects of milling fractions of bread wheat when used as food media on the biology of *Cryptolestes turcicus* and *Cryptolestes ferrugineus*. Most of the experiments were done in the laboratory at controlled temperature and relative humidity. One experiment was done in a flour mill where adults of both species were caged in sealed tins in the machines.

A total of three grades of four milling fractions were used as food media throughout the investigation. At certain levels of temperature and relative humidity the foods significantly altered the rate of development, survival, or fecundity of both species of insects. In the laboratory, under controlled conditions of temperature and relative humidity which were equivalent to those obtained in mill stocks in milling machinery, both *C. turcicus* and *C. ferrugineus* produced the most offspring in 30 days on the tailings fraction, fewer on the break and low grade and much fewer on the middlings fraction. When reared individually in the laboratory, *C. ferrugineus* larvae developed

more rapidly than did C. turcicus larvae.

When reared in sealed containers suspended within the milling machinery, C. turcicus produced roughly half as many offspring as did C. ferrugineus. C. turcicus increased most rapidly under these conditions on the break fraction, fewer on middlings, low grades and tailings in descending order. Middlings was the best food medium for the increase of C. ferrugineus; tailings, low grades and breaks were less suitable. This order of fractions as they affected the increase of C. ferrugineus is different than most of the other results, and may be due to the fact that the containers used to hold the insects were sealed.

It is an established fact that C. turcicus is an economic pest in flour mills in temperate regions of the world. The comparative results obtained in this investigation indicate that on the basis of the three criteria - rate of development, survival and fecundity - as determined in the laboratory, C. ferrugineus may also become a mill pest in these regions.

On the basis of rate of development of C. turcicus, fumigation or cleaning of mill machinery would have to be repeated once every four weeks if each generation of the insect was to be controlled. Machines containing tailings and low grade stocks would probably be the first to show the presence of a buildup in population of C. turcicus.

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CHAPTER I

INTRODUCTION

The Food and Agriculture organization of the United Nations has estimated that ten per cent of the world's food supply is destroyed by insects each year. Much of this loss is caused by insects that attack stored grain and cereal products. There may be further loss of food through contamination by insect fragments and excreta which can render the food unfit for human consumption.

Much of the loss currently suffered by the grain and milling industry may be eliminated by raising mill sanitation standards and improving storage techniques. Gray recently stated "survival of the cereal product manufacturer in this highly competitive field will depend in no small part on his ability to meet the rising standards of mill sanitation" (1950). Mill sanitation is becoming more important as world markets expand and Canadian grain and milled cereal products compete with products from other countries.

The problem

The purpose of this study was to attemp to learn something of the effects of milling fractions as food on the biology of the flat grain beetle *Cryptolestes turcicus* (Grouv.) and the rusty grain beetle *Cryptolestes ferrugineus* (Steph.). A review of the literature has produced fragmentary information on the life history and habits of *C. turcicus*. In addition, most of the published results are based on laboratory investigations where the food media were limited to wheat or wholemeal flour plus yeast, and therefore cannot be related to actual mill conditions.

The biology of *C. ferrugineus* has been investigated by several workers (Rilett, 1949; Bishop, 1959; Smith, 1962) who have reported on the life history of the insect as determined in the laboratory. It is not known whether this insect can become established in flour mills in temperate regions of the world.

Importance of the study

Cryptolestes turcicus is an important pest of flour mills in Canada and many other milling centers of the world. *Cryptolestes ferrugineus* is a mill pest in the tropics and an important pest of stored grain in temperate regions. It is presently believed that this insect may gain access to milling machinery with incoming wheat. To develop the most effective methods of control for both these species of insects, it is essential first to learn the life history and habits of the pest.

Some workers feel that moisture is the most important factor governing where large populations of *C. turcicus* may build up in milling machinery and that nutritive value of the milling fraction has little consequence in this regard (Dyte, 1960). This thesis reports on an investigation of the effects of milling fractions of bread wheat when used as food media on the rate of development, survival and fecundity of *C. turcicus* and *C. ferrugineus* at various levels of temperature and relative humidty with a view towards improved control measures for *C. turcicus* and an assessment of the possibility of *C. ferrugineus* becoming a mill pest in temperate regions of the world.

Organization of the thesis

Most of the experimental work was done in the laboratory. By rearing both species on three grades of four milling fractions it was possible to investigate the effect of food on rate of development, survival and fecundity; the relative importance of environmental factors such as temperature and relative humidity and nutritional factors such as food type and particle size on the rate of increase of the species.

Both species were also reared under actual flour mill conditions. This allowed a comparison with results obtained in the laboratory and also permitted a more valid assessment of the possibility of *C. ferrugineus* becoming a mill pest in temperate regions.

Comparative biological information concerning the two species and a short description of the process of milling wheat have been included to orientate the reader.

The chapter dealing with general literature has been set apart, while literature dealing with the specific areas of the present investigation has been included in the discussion of the appropriate chapters.

CHAPTER II

REVIEW OF GENERAL LITERATURE

There are three species of the genus Cryptolestes, namely C. ferrugineus, C. turcicus and C. minutus (Ol.) that are pests of stored grain and/or milled cereal products in North America (Bishop, 1960). There has been some taxonomic uncertainty in this genus and in certain species of the genus. Prior to 1955, the above mentioned species were in the genus Laemophloeus (family Cucujidae), but in that year the species of the genus which attacked stored products were placed in the genus Cryptolestes (Howe and Lefkovitch, 1957). Some of the confusion over species resulted from the difficulty of separating C. minutus and C. turcicus (Cotton, 1950; Howe and Lefkovitch, 1957). Watters (1953) referred to C. pusillus (Schonl.) (minutus) when, in reality, he was probably dealing with C. turcicus. Reid (1942) listed the morphological characteristics which could be used to separate the adult insects and Bishop (1960) outlined the morphology of the larvae.

Surveys conducted in the United States have shown that species of Cryptolestes are common in stored grain. Flat grain beetles were among the most common species of insects in samples from grain elevators in Oregon (Swenson and Tunnock, 1957) and were also caught in traps located near a wheat storage area in Kansas (Cotton et al, 1953). A survey of some California granaries indicated that C. ferrugineus and C. minutus were secondary pests which were encountered a little less frequently than were flour beetles and saw-toothed grain beetles (Linsley and Mickelbacher, 1943). C. minutus was among the most common of five species recovered in rotating traps in a grain storage area in Kansas (Schwitzgebel and Walkden, 1944). Cryptolestes spp. were found in 45 of 544 ships entering the ports of Montreal, Sorel, Three Rivers and Quebec City during 1948 and 1949 (Monro, 1951). During 1944, 1945 and 1946, a total of 25 of 100 ships used in international trade, and which called in England, were found to be infested with one or more species of flat grain beetles (Freeman, 1947). Howe and Lefkovitch (1957) identified Cryptolestes spp. collected on ships of American origin in British ports and recorded 116 occurrences of C. ferrugineus and 23 of C. turcicus. Of 30 collections of C. turcicus found in produce from various parts of the world, Howe (1955) reported that 14 were from North America.

Howe and Lefkovitch (1957) have shown C. turcicus to be present in flour mills in England, Uruaguay, Argentina, U.S.A., Morocco, Algeria, Greece, Tunisia and Turkey, while Salmond (1956) recovered C. ferrugineus, C. turcicus and C. minutus from a flour mill in Scotland. In this instance however, he referred to C. minutus as a secondary pest and did not comment on the importance of the other two. Howe

(1955) stated that C. turcicus was common in Europe, and although it was especially abundant in flour mills in Britain, it was seldom found in any other kind of premises. He also indicated that there was relatively little reliable published information on the world distribution of this species. C. turcicus was first noted on a window in a flour mill in England by Joy in 1925, but was not recorded as being in a flour mill stream in England until 1950 (Williams, 1950). Lefkovitch (1962) stated that C. turcicus is fairly common in provender mills in England, but is not present in flour mills in the tropics. Howe and Lefkovitch (1957) said C. ferrugineus had been recovered from mill machinery on several occasions in Britain, and Lefkovitch (1962b) indicated that it is the common mill pest in tropical countries. It has been suggested by Howe and Lefkovitch (1957) that "the food and environment in machines of flour mills gives C. turcicus some advantage for survival over other species of Cryptolestes".

Several species of Cryptolestes have been recorded as pests in flour mills in the United States. Shepard (1947) stated that C. minutus was the most common of the genus in flour mills while C. ferrugineus was less common but fed on flour or meal as did C. minutus. He recorded C. turcicus from one mill in Minneapolis. Cotton (1950) stated that C. minutus and C. turcicus which is very similar in appearance to C. minutus were not primary pests but were scavengers which fed on grain and meal which was out of condition, and on this type of food the species could become abundant in mill boots and sifters. According to Cotton (1950), C. ferrugineus was more common in grain in the Northern States. A winter survey of flour mills in the Buffalo, New York area showed C. ferrugineus and C. minutus to be present in unheated mills and more common than C. turcicus (Rilett and Weigel, 1956).

C. turcicus is commonly found in flour mills throughout Canada (Liscombe, unpublished data) but C. ferrugineus is rarely found. C. turcicus has been recovered from elevator dust bins in rural Manitoba, but it was not recovered in a survey of farm granaries in the Prairie Provinces (Liscombe and Watters, 1961).

A recent survey of stored grain in the State of Washington showed C. turcicus was rarely found (Walker, 1960), while Cotton (1962) stated this species often infested stored grain in the Northern States. Bishop (1959) found the species in stored grain in 12 States of the United States and the Province of British Columbia. Lefkovitch (1962c) referred to North America as the only part of the world where C. turcicus would breed on unprocessed grain.

C. ferrugineus has been reported as the most serious pest of stored grain in Western Canada (Anon., 1943; Anderson, 1956; Watters, 1959). It has also been common in stored grain in Minnesota, North and South Dakota and Montana (Butler and Mickel, 1955) and the Willamette Valley of Oregon (Walker, 1960). Farrar and Flint (1942) stated that C. ferrugineus was one of the six species of insects which resulted in the most acute storage problems with shelled corn in Illinois. Specimens of Cryptolestes spp. captured in traps in a raisin storage yard in California (Barnes and Kaloostian, 1940) were later identified to be C. ferrugineus by Bishop (1959). The rusty grain beetle is common in grain and stored products in England (Howe, 1951), in English granaries (Coombs and Freeman, 1956) and in various products from N. Nigeria (Howe, 1952) and S. Nigeria (Cotterer, 1952). Lefkovitch (1962b) stated that C. ferrugineus gains access to milling machinery with incoming grain.

The true importance of Cryptolestes spp. in grain and cereal products lies in the actual damage they cause. It is difficult to assess the damage by species that infest flour mills as it is impossible to determine the amount of food consumed or contaminated (Lefkovitch, 1962b). Present Food and Drug laws prohibit the marketing of contaminated food for human consumption, and a badly infested mill may be closed down if it can be proven that it is producing adulterated food.

It is much easier to realize the damage done to stored grain due to the presence of species of Cryptolestes which cause grain to heat. This phenomenon was attributed to the genus as a whole (Freeman, 1948, 1952; Howe, 1943; Oxley and Howe, 1944) as well as to the species C. ferrugineus and C. minutus (Anon., 1961).

One of the questions concerning insects which attack stored grain is whether or not the pest is considered to be primary or secondary. Primary pests are those that attack sound grain and cause heavy losses. Secondary pests cannot attack sound grain and generally follow or are found in association with primary pests. Secondary pests are considered less dangerous from the standpoint of economic loss than are primary pests.

Fraenkel and Blewett (1943), Davies (1949), Rilett (1949), Cotton (1950) and Freeman (1952) stated that various members of the genus Cryptolestes are unable to feed on sound grain, thus relegating them to a secondary roll. Butler and Mickel (1955) found on microscopic examination of 1000 sound kernels of No. 1 Northern spring wheat that 52.8 per cent had fissures over the germ large enough to permit oviposition by flat grain beetles. They suggested that Cryptolestes spp. were not dependent on the presence of other insects for establishment and could, therefore, be considered primary pests of stored grain. Lucas and Oxley (1946) found immature forms of flat grain beetles living within the kernels of wheat and not visible to the naked eye. It is now well established that at least C. ferrugineus is a primary pest in Canada

(Anon., 1943; Anderson, 1956; Watters, 1959; Liscombe and Watters, 1962).

The country of origin of C. turcicus has been questioned by several workers. Howe and Lefkovitch (1957) stated the species was probably native to Turkey and may have entered flour mills in the Mediterranean area by flight and thence to Britain on imported flour; or on wheat imported from the United States. After conducting a survey of recorded information, Davies (1949) stated that C. turcicus was cosmopolitan in distribution while Howe (1955) refuted this assumption as there was little reliable published information on the distribution of the pest. Lefkovitch (1962c) stated, "on intuitive grounds I believe it to be a North American species".

CHAPTER III

GENERAL METHODS AND MATERIALS

Collecting, rearing and handling of laboratory insect cultures

Adults of each species of insect used throughout this investigation were obtained from laboratory cultures started from separate sources in Manitoba. Original individuals for the culture of *C. turcicus* were obtained from a flour mill in Virden. The individuals for the *C. ferrugineus* culture originated in the annex of a commercial country elevator at Gretna.

Stock cultures of *C. turcicus* were reared on patent flour to which had been added five per cent by weight of finely ground wheat germ. Stock cultures of *C. ferrugineus* were reared on 2 Northern spring wheat conditioned with water to give a moisture content of 16 per cent. Containers consisted of wide mouthed gallon jars fitted with filter paper lids which were sealed on with hot paraffin.

The moisture content of the wheat used for the cultures of *C. ferrugineus* was determined with a Halross dielectric moisture meter[1]. Anderson (1956) reported that the standard error of estimate of this meter, compared with the Brown-Duval method, was 0.27 per cent in 554 samples of wheat with moisture contents ranging from 12.2 to 17.6 per cent.

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[1]Canadian Aviation Electronics Ltd., Winnipeg, Manitoba

The cultures were kept in rearing cabinets maintained at 80±1°F. and approximately 75 per cent relative humidity.

To obtain adults for the various experiments, the food medium in the stock cultures was sieved through screens of various size mesh to concentrate the insects in a small amount of the food medium. With *C. ferrugineus*, the concentrated medium containing the adults was piled on top of an inverted petri dish in a tray. The adults quickly crawled to the edge of the dish and fell to the tray below. With *C. turcicus*, the concentrated medium was placed on a piece of white paper which was shaken to remove the medium and pupal cases while the adults and larvae clung to the paper. The adults were picked from the paper with a camel hair brush.

Eggs of both species were obtained by placing adults in flour which had previously been passed through a 100 mesh to the inch sieve. The eggs were removed each day by passing the egg laying medium through an 80 mesh to the inch sieve. This allowed the flour to pass through readily and the eggs were retained.

Early in the course of the investigations the stock cultures of both species became infested with mites. When this occurred, the adult insects were separated from the mites with fine sieves and new cultures were set up. The culture containers were later set on metal legs in a tray of number ten motor oil, after which there were no further difficulties with mites.

Sexing of C. turcicus was based on length of antennae since the antennae in the male are longer than in the female. A petri dish containing the adults was placed on a white background and individuals of each sex were sorted out with a camel hair brush.

Adults of C. ferrugineus were sexed by the method described by Rilett (1949). The beetles to be sexed were placed in a small petri dish which rested in a larger dish containing cracked ice. As soon as the floor of the dish became chilled the beetles became inactive. With the aid of a microscope, the males were separated from the females on the basis of differences in mandibles, as the male adult possesses a spine at the base of the mandible which is missing in the female. In cases where doubt existed as to the sex of a particular insect, light pressure was applied to the ventral part of the abdomen by means of a blunt pair of forceps. If the beetle were a female, the styli and substitutional ovipositor were extended. When carefully executed, this procedure did not harm the insect.

Collecting and handling of experimental food media

Three grades of four milling fractions were used throughout the investigation. Samples of these mill stocks were collected in a local flour mill. They were taken directly below the rolls of machines designated as follows:

First break	Third break	Fifth break
First middlings	Third middlings	Fifth middlings
First tailings	Fourth tailings	Germ tailings
First low grade	Second low grade	Third low grade

The samples were all taken from the same mill run to eliminate possible differences between runs and were stored at 20°F. until required. Portions of these samples were chemically analysed for protein, ash, fiber and fat content. Prior to being used for an experiment, all foods were conditioned for a period of seven days at the temperature and relative humidity of the experiment in desiccators containing appropriate solutions of KOH for humidity control (Buxton and Mellanby, 1934).

For all tests that required a fine particle size the food media were ground in a Wiley Mill[1]. A 0.5 mm. brass screen was used in the machine to obtain a fine particle size without changing the moisture content appreciably. This reduced the period of time required to condition the food to the level of moisture required for experimental work. The food media were ground rather than sifted so that the chemical composition of the fractions would not be altered.

Where possible, the experimental data were analysed statistically (Snedecor, 1948).

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[1]Arthur H. Thomas Co., Philadelphia. Standard Model No. 3

CHAPTER IV

THE PROCESS OF MILLING WHEAT

The wheat kernel consists of endosperm, bran and germ in the approximate ratio of 84:14:2. These parts and their composition are depicted in Figure 1.

The process of milling wheat consists of gradually reducing the kernel of wheat into flour, the objective being to separate the endosperm from the other components in as pure a form as possible.

Moisture content of wheat to be milled is raised to approximately 15.5 per cent by the addition of water. This gives a tough bran coat which will hold together upon grinding, and a mellow endosperm that is readily crushed. Wheat is ground by passing it between pairs of heavy rolls. The first break roll merely cracks open the kernel which then passes through a sifter designed to separate fragments according to size. The coarsest fragments go to the second break roll which grinds them a little finer. The process of alternately grinding and sifting is repeated four to six times depending on the mill, thus providing four to six breaks. For each successive break, the rolls are set a little closer together, and the stock is ground a little finer. Below each set of break rolls is a sifter which classifies particles according to size. A generalized mill flow sheet

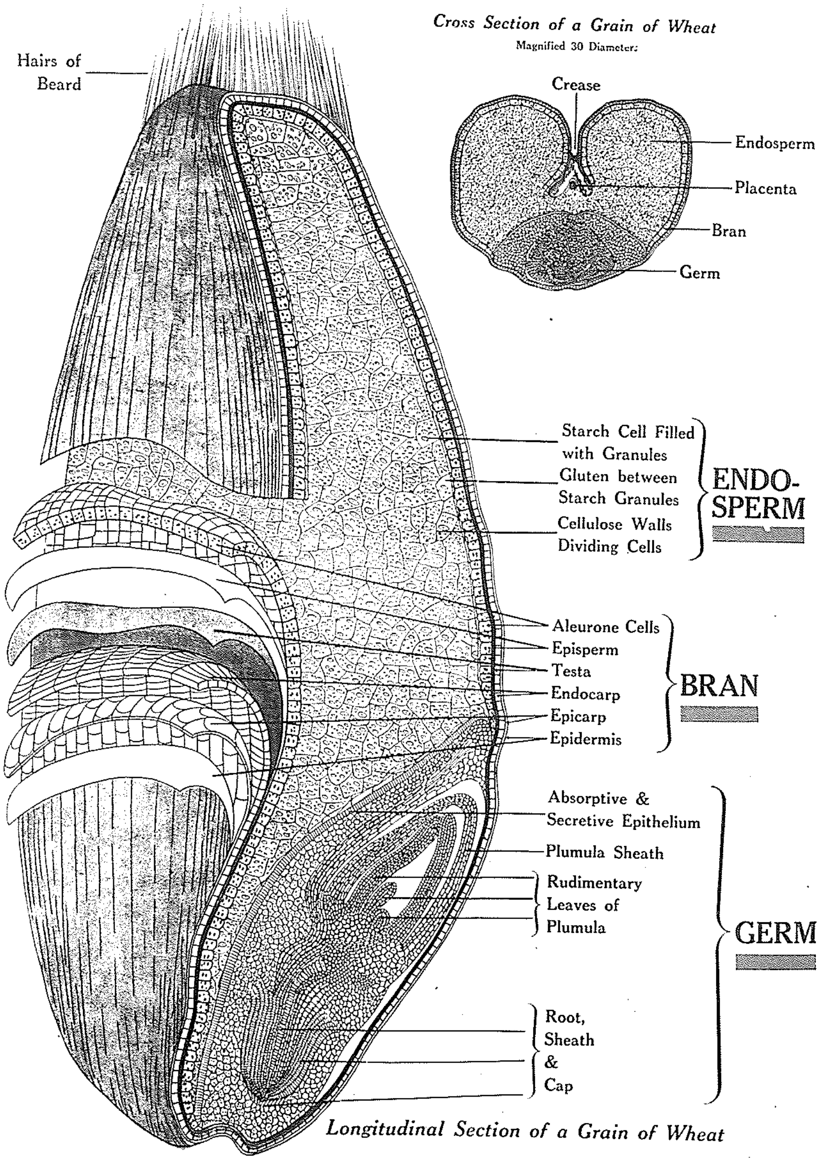

Figure 1. Diagrammatic view of component parts of the wheat kernel.

is shown in Figure 2.

The purpose of the break system is not to make flour, but to liberate endosperm in the form of middlings which can then be dealt with in a reduction system. This is a gradual process of grinding, similar to the break system, with the endosperm finally being ground into flour.

The germ is largely released by the break rolls and appears as yellow particles in the coarser middlings. It is not removed by the purifiers but, being soft, it is flattened out when the middlings are reduced, and in this flaked condition can be separated by means of sieves. Only a small part of the germ can thus be recovered in a pure form.

The stock coming from the break sifters (with the exception of the coarsest material going to the next set of rolls) is called middlings and consists of particles of endosperm and small pieces of bran. The bran is largely removed by means of machines called purifiers. In these machines, the bran-endosperm mixture travels down a long slightly inclined silk sieve through which a current of air is drawn. Rapid shaking of the sieve causes the material to move in a series of small waves, and, as it travels from the head of the purifier, the heavier particles consisting of pure endosperm work to the bottom of the shallow layer and fall through the meshes of the sieve against the upward current of air. On the other hand, the light branny particles are held

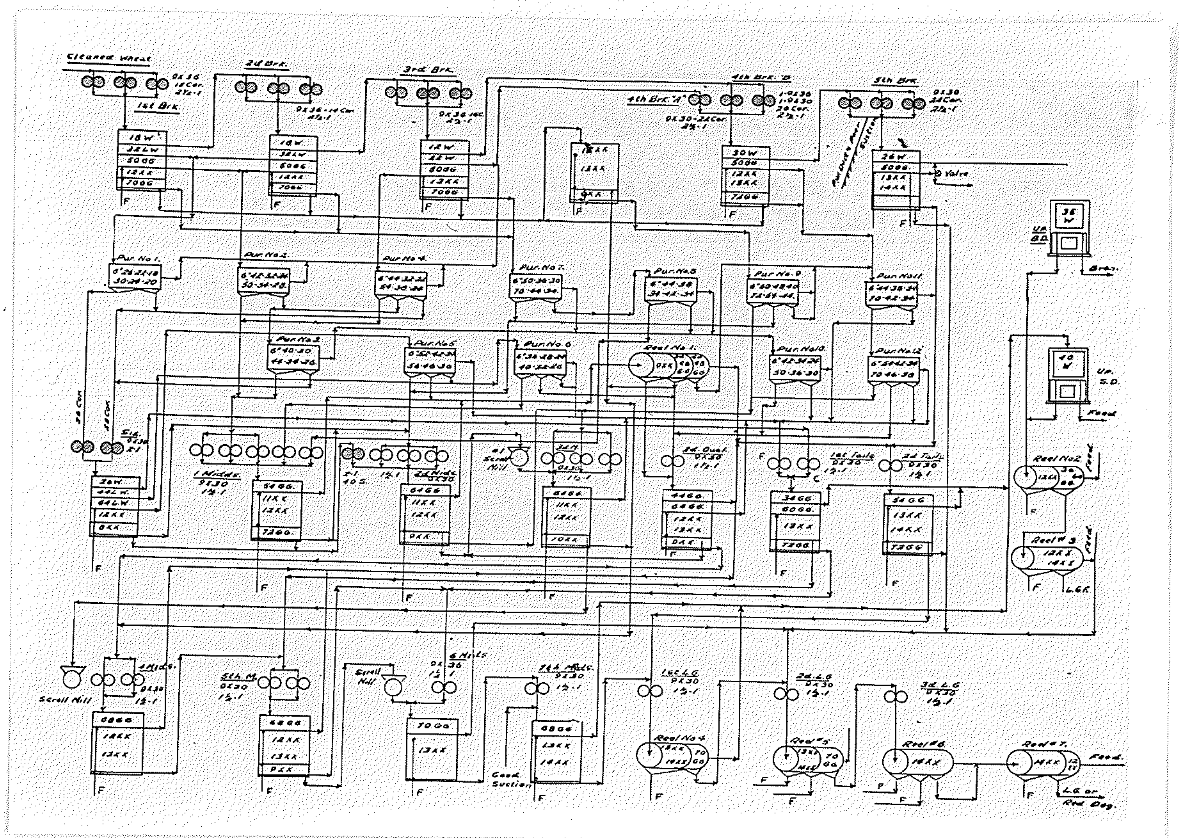

Figure 2. Schematic diagram of a general mill flow sheet.

in suspension by the air current and tend to float on the surface of the stream to finally tail over the end of the sieve.

Tailings consist of the tailovers of some of the purifiers and of scalp clothes of sifter sections below the rolls. Material going to the first tailings roll carries a high percentage of germ which is removed at this time.

Low grades are the latter reductions of middlings and contain endosperm, bran chips and germ. Shorts is made up of a mixture of small particles of bran, germ and endosperm which cannot be further treated, at least not economically.

There is no standardized naming of the various portions of the partially ground wheat kernel called stocks. Consequently, stocks bearing the same name but produced in different mills may be different in physical and chemical properties. Most mills use the general fraction classification of breaks, middlings, tailings and low grades. Each of these fractions consists of several grades, the number of grades being dependent upon the size of the mill and the number of roll stands. Chemical analysis for protein, ash, fiber and fat content as well as the moisture content of the three grades of each of these four fractions used in the present investigation are listed in Table I.

The term extraction rate is used to signify the amount of flour produced from a given amount of wheat. In Canada, the extraction rate of 73.7 per cent generally used means

TABLE I

MOISTURE CONTENT AND CHEMICAL DETERMINATIONS OF PROTEIN, ASH, FIBER AND FAT CONTENT OF THREE GRADES OF FOUR MILLING FRACTIONS'

Fraction	Grade	Moisture %	Protein %	Ash %	Fiber %	Fat %
Break	First	15.1	13.8	1.6	2.2	1.7
	Third	15.7	15.6	3.4	4.8	3.0
	Fifth	15.5	15.2	5.5	8.9	4.5
	Mean	15.4	14.9	3.5	5.3	3.1
Middlings	First	14.9	12.0	0.5	2.1	9.0
	Third	13.3	12.3	0.5	2.4	9.5
	Fifth	13.8	12.2	0.7	3.7	1.3
	Mean	14.0	12.2	0.6	2.7	6.6
Tailings	First	14.4	13.8	1.8	1.6	3.0
	Fourth	13.3	14.5	2.1	2.0	3.0
	Germ	12.5	16.1	2.8	2.9	4.7
	Mean	13.4	14.8	2.2	2.2	3.6
Low grade	First	12.7	14.3	1.4	1.2	2.2
	Second	12.4	14.3	1.5	1.3	2.2
	Third	11.9	14.5	2.0	2.0	2.8
	Mean	12.3	14.4	1.6	1.5	2.4

that 100 pounds of wheat are used up as follows:

Mill screenings (weed seeds etc.)	1.5 pounds
Bran	11.0 "
Shorts	13.5 "
Germ	0.3 "
Flour	73.7 "
Total	100.0 "

During the milling process the temperature of the atmosphere within the mill building is an important factor at all times as it influences the temperature of the stocks. For proper grinding, the miller likes to keep the temperature of the break fraction as close to 75°F. as possible. Due to the heat produced by the grinding process it is not always possible to keep the temperature at this level. Temperature readings were taken of the stocks within the roll stands on the roll floor in a local flour mill in October to give some idea of the average temperature of the fractions (Table II). Air temperatures taken on the roll floor were gathered for each day the mill was in operation during the period March 1 to October 15, 1963 (Table III).

TABLE II

TEMPERATURE OF MILL STOCK TAKEN FROM WITHIN THE MILLING MACHINERY FOR EACH OF FIVE WEEKS

Fraction and grade	Week					Total	Mean
	1	2	3	4	5		
1 Break	84	86	85	83	84	422	84.4
3 Break	90	88	90	86	88	442	88.4
5 Break	93	86	93	92	90	454	90.8
Mean							87.9
1 Middlings	84	88	85	85	86	428	85.6
3 Middlings	86	97	91	92	90	456	91.2
5 Middlings	92	84	95	93	91	455	91.0
Mean							89.3
1 Tailings	91	88	91	90	90	450	90.0
4 Tailings	90	88	86	88	88	440	88.0
Germ tailings	93	88	91	92	90	454	90.8
Mean							89.6
1 Low grade	90	88	88	86	88	440	88.0
2 Low grade	95	88	91	90	91	455	91.0
3 Low grade	90	88	91	90	90	449	89.8
Mean							89.6

TABLE III

AIR TEMPERATURES TAKEN ON THE ROLL FLOOR OF A WINNIPEG FLOUR MILL EACH DAY THE MILL WAS IN OPERATION DURING EIGHT MONTHS OF 1963

Day	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
1	85	84	84	84	81	85	81	86
2	85	83	82	85	86	89	85	85
3	83	82	83	83	86	85	87	83
4	82	82	84	86	88	86	83	86
5	83	82	83	86	88	82	84	85
6	81	82	81	81	89	83	86	84
7	84	83	83	82	87	83	81	84
8	84	82	82	82	86	83	82	85
9	84	82	83	83	85	82	83	84
10	82	82	85	84	85	88	83	85
11	84	82	86	86	84	87	82	83
12	84	84	85	84	85	85	82	86
13	84	82	82	82	87	81	84	87
14	81	83	83	84	88	83	82	87
15	82	82	84	90		83	84	87
16	85	85	84	84		83	85	88
17		83	85	87		82	86	87
18		83	83	88		83	87	85
19			83	90			84	84
20			82				84	84
21			81				85	85
22			85					87
23			84					82
24								84
25								83
26								85
27								84
28								84
29								85
Mean	83.5	82.7	83.3	84.8	86.1	84.1	83.8	85.0

CHAPTER V

DESCRIPTION AND BIOLOGY OF *Cryptolestes turcicus* (GROUV.).

The life history of *C. turcicus* is similar to that of *C. ferrugineus* (Rilett, 1949), *C. minutus* (Davies, 1949) and *C. ugandae* Steel and Howe (Lefkovitch, 1957). Lefkovitch (1962) and Bishop (1959) referred to the biology of *C. turcicus* but neither author gave much detail of the various stages.

Eggs are deposited loosely in the food material and the incubation period depends on the temperature and relative humidity of the environment. Segmentation of the larva can be seen just prior to emergence from the egg. By a series of stretching and undulating movements the chorion is broken and the larva emerges. The caudal hoods or "egg bursters" are used to assist the young larva to escape from the egg shell.

There are four larval instars. During the late third or early fourth instar, a pair of silk glands begins to develop on the ventral surface of the first thoracic segment (Bishop, 1960). The silk glands develop rapidly, and shortly before the onset of the prepupal stage in the latter part of the fourth instar, a cocoon is spun. The cocoon may take several forms. In fine food medium such as flour, the cocoon may be formed entirely of silk, while in coarse food medium the cocoon usually consists of particles of food held together and lined with the silken material. The larva will occasionally pupate without forming a cocoon. The pupa emerges anteriorly through the split larval skin of the fourth instar larva. The duration of the larval period varies greatly, depending on the temperature and relative humidity at which the insect is reared (Lefkovitch, 1962). The adult remains within the pupal case for about two days and then chews its way out of the cocoon (Figure 3). It soon commences to feed and search for a mate.

Description of stages

Bishop (1960) published a taxonomic description of the larvae of *C. turcicus*, *C. ferrugineus* and *C. minutus* and outlined a key for their separation.

Egg

The egg of *C. turcicus* is sausage-shaped and glistening white when laid, but becomes yellowish and opaque just before eclosion. It is slightly more than three times longer than wide with one end more tapered than the other. The eggs of this species are very similar in appearance to those of *C. ferrugineus*. The dimensions of ten eggs of each species are given in Table lV. The incubation period and mortality of the egg vary with temperature and relative humidity (Table V).

Larva

The newly hatched larva is whitish and slightly longer

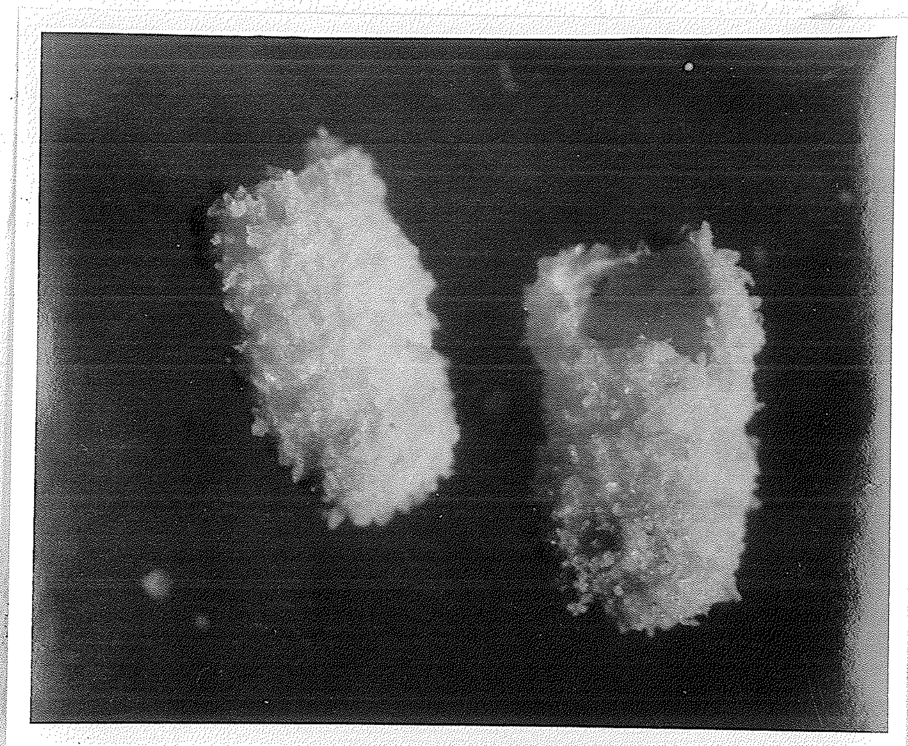

Figure 3. Cocoons of C. turcicus from which new adults have emerged.

TABLE IV

COMPARATIVE SIZE (MM.) OF EGGS OF *C. turcicus* AND *C. ferrugineus*

Egg No.	*C. turcicus*		*C. ferrugineus*	
	Length	Width	Length	Width
1	0.51	0.17	0.78	0.20
2	0.55	0.17	0.78	0.20
3	0.56	0.17	0.71	0.30
4	0.58	0.17	0.78	0.23
5	0.58	0.18	0.78	0.20
6	0.57	0.18	0.78	0.20
7	0.59	0.18	0.75	0.23
8	0.51	0.17	0.68	0.27
9	0.62	0.19	0.81	0.20
10	0.59	0.18	0.78	0.23
Mean	0.57	0.18	0.76	0.23

TABLE V

EFFECT OF TEMPERATURE AND RELATIVE HUMIDITY ON INCUBATION AND MORTALITY OF EGGS OF *C. turcicus*

Temperature (°F.)	Relative humidity			
	80 Per cent		50 Per cent	
	Egg stage (Days)	Mortality (Per cent)	Egg stage (Days)	Mortality (Per cent)
100	-	100	-	100
95	3	0	-	100
90	5	17.5	3	56.0
70	5	4.0	5	12.0
60	12	25.0	11	10.0

than the egg. There are four instars, the last of which is partly spent as a prepupa. In this condition the larva is shortened, thickened and completely immobile.

Pupa

The new pupa is white with light brown eyes. The mandibles darken first followed by the gradual darkening of the remainder of the body.

Adult

The beetle is light amber in color when formed. It remains in the cocoon until the exoskeleton has hardened and the body has attained its normal red-brown color. The species shows sexual dimorphism with the male antennae being as long as the body and the female antennae half the body length.

Flight habits

Observations in the laboratory and in flour mills have shown that the adults of *C. turcicus* are fairly strong fliers. As the air temperature approaches 80°F., adults separated from their food appear excited with frequent flexing of the elytra and partial extension of the hind wings. As the temperature rises above 80°F., the insects will take off and fly upwards, usually veering off in the direction of the windows. Literally hundreds of adults have been found on windows in an unused flour mill, indicating that as food became scarce and the temperature exceeded 80°F. the adults left their habitat in search of new surroundings. Bishop (1959) noted that under identical conditions the tendency to fly appeared to be stronger in C. ferrugineus than in C. turcicus. This is the reverse of observations made during the current studies. It is possible that C. turcicus found in flour mills in Canada are a different strain than the grain infesting forms found by Bishop (1959) in the Pacific Northwest of the U.S.A.

Cannibalism

Lucas and Oxley (1946) reported adults of Cryptolestes spp. to be cannibalistic but not larvae. Lefkovitch (1957) observed cannibalism in cultures of C. ugandae when larval density was high. Ashby (1961) and Rilett (1949) said C. ferrugineus was cannibalistic and Lefkovitch (1962a, 1962b) reported the same characteristic for C. turcicus. In the present investigations, C. turcicus larvae were found to be extremely cannibalistic as population density increased beyond a certain point. The tough silken cocoon referred to by Lefkovitch (1962a) was no obstacle to the larva (Figure 4, 5).

Biology

Lefkovitch (1962a) studied the rate of development of

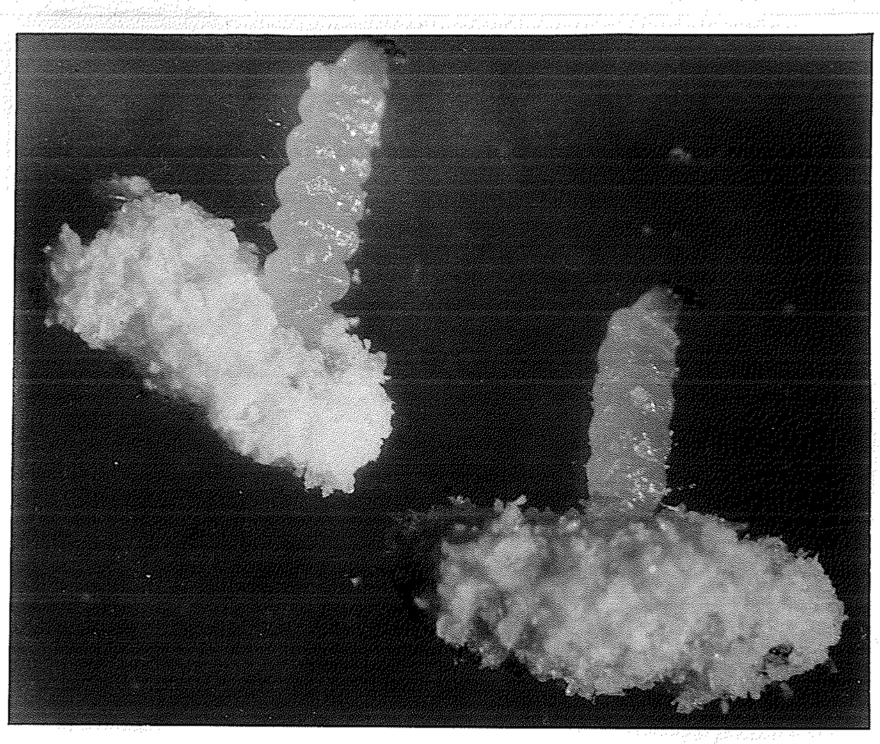

Figure 4. C. turcicus larva feeding on the pupa within the cocoon.

Figure 5. A number of cannibalized cocoons taken from a densely populated culture of C. turcicus.

C. turcicus reared on wheatfeed. Development was most rapid at 95°F. and 90% R.H., the life cycle minus the incubation period of the egg requiring 25.8 days. Survival however, was only 20 per cent. At the same relative humidity the greatest survival was 73.3 per cent at 72°F. and the least was 16.7 per cent at 63°F.; the duration of development being 44.3 days at 72°F. and 141.3 days at 63°F. The range of temperature at which the insect could complete development when the relative humidity was reduced to 70 per cent was narrowed to 72°F. to 90°F. At 70% R.H. the rate of development at each temperature was slower than that observed at the higher humidity, the shortest time being 34.5 days at 90°F. and the longest being 60.7 days at 72°F. Survival at 70% R.H. ranged from 23.3 per cent at 86°F. to 76.6 per cent at 72°F. At 50% R.H. all larvae died at 72°F. and 90°F., but there was 66.7 per cent survival at 81°F.

Bishop (1959) studied rate of development of *C. turcicus* on food consisting of one-half a wheat kernel containing germ. At 90°F. and 90% R.H., the average time required to complete development (first instar larva to adult) was 25.2 days, while at the same temperature but at 70 and 50% R.H. all first instar larvae died. The discrepancy in the results may be due to food. The results of Bishop (1959) may not reflect the ability of the species to survive because of the choice of food.

For oviposition studies, Bishop (1959) used flakes of wheat germ as food and Lefkovitch (1962a) used wheatfeed. At 90°F., Bishop (1959) reported a lifetime average of 53.6, 6.6 and 0.5 eggs per female at 90, 70 and 50% R.H., respectively. At 70°F., he reported a lifetime average of 131.0, 21.8 and 5.8 eggs per female, respectively, at 90, 70 and 50% R.H. on food consisting of equal parts of wholemeal flour and wheat germ. Lefkovitch (1962a) reported a 12 week total of 102.5 eggs per female at 90°F. and 90% R.H., 112.9 at 82°F. and 90% R.H. and 90.4 eggs at 82°F. and 70% R.H.

Lefkovitch (1962a) claimed the optimum conditions for C. turcicus to be near 82°F. and 90% R.H., while Bishop (1959) stated the optimum may be near 70°F. and 90% R.H.

CHAPTER VI

COMPARATIVE BIOLOGY OF *C. turcicus* and *C. ferrugineus*

The biology of *C. ferrugineus* has been described by Rilett (1949). The life cycle and the appearance of the life stages are similar to that of *C. turcicus* and it is extremely difficult to differentiate between the immature forms of the two species. Both species may form similar cocoons (Figure 6) but *C. ferrugineus* usually forms only a cell (Figure 7). Occassionally *C. ferrugineus* pupates in a naked condition. The males and females of *C. ferrugineus* can be separated by a prominent tooth at the base of the mandible of the male, and by the tarsal formula which is 5-5-4 for males and 5-5-5 for females.

Evidence of cannibalism in *C. turcicus* has been presented; Rilett (1949) reported that *C. ferrugineus* possessed the same characteristic. I have not seen a *C. ferrugineus* larva attacking another live larva but many dead larvae which had been cannibalized were observed in cultures (Figure 8). This may simply indicate that *C. ferrugineus* is a scavenger and not a cannibal.

Temperature affects the incubation period of the egg of *C. ferrugineus* in a manner similar to that of *C. turcicus* but it appears from examining the data of Rilett (1949) that at comparable temperatures the eggs of *C. turcicus* develop

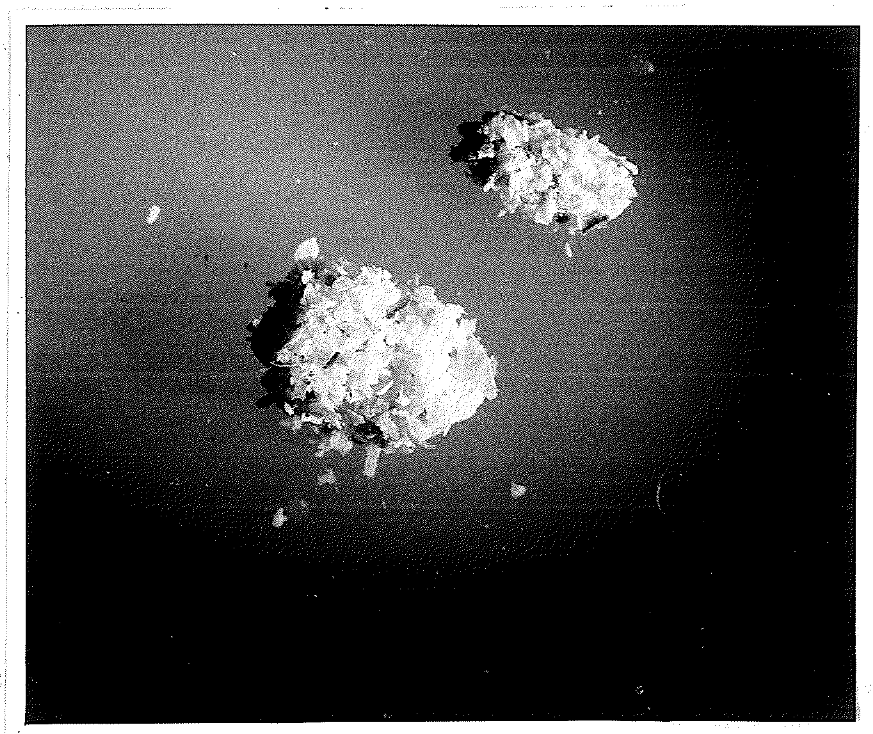

Figure 6. Comparative size and shape of cocoons formed by *C. turcicus* and *C. ferrugineus* (larger one is *C. ferrugineus*.

Figure 7. Type of cell formed by C. ferrugineus when complete cocoon is not formed.

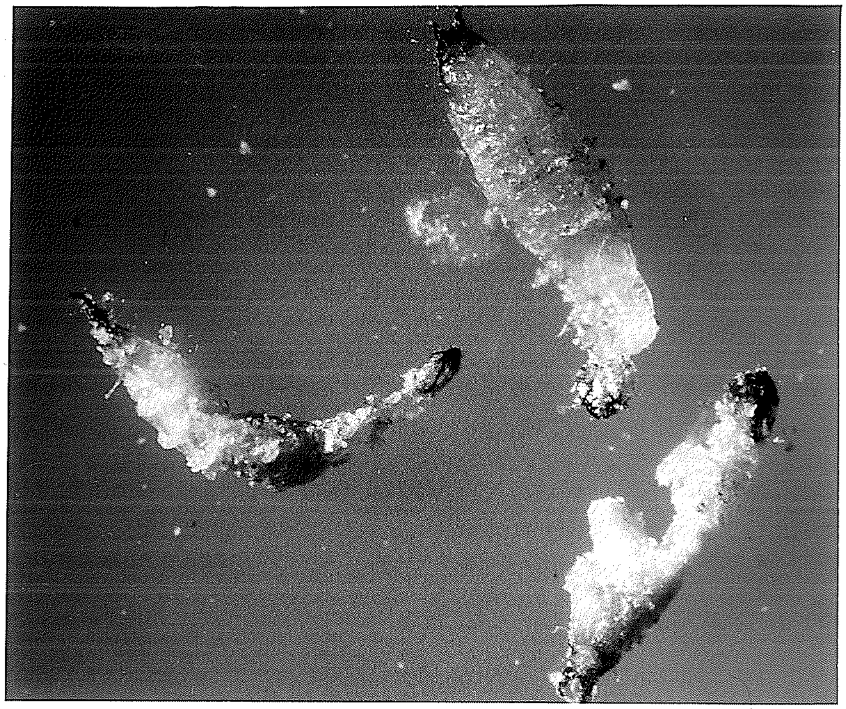

Figure 8. Typical appearance of cannibalized larvae of *C. ferrugineus*.

somewhat faster than those of *C. ferrugineus*.

Rilett (1949) reported that *C. ferrugineus* developed most rapidly on wheat with germ and most slowly on white flour. Using split wheat kernels as food, Bishop (1959) observed that at 90°F. the period of development of *C. ferrugineus* was shorter at 90% R.H. than at 70% R.H. and all first instar larvae died at 50% R.H.

Bishop (1959) compared the oviposition rates of the two species when reared on flakes of wheat germ. He found that at 90°F., *C. turcicus* laid a few more eggs than did *C. ferrugineus* at 90% R.H., but *C. ferrugineus* laid several times more eggs than *C. turcicus* at relative humidities below 90 per cent. For oviposition, *C. ferrugineus* appears to be less sensitive than *C. turcicus* to reduced relative humidity.

Bishop (1959) determined the average number of progeny per female of both species at various temperatures and relative humidities. He found that *C. turcicus* produced more progeny than *C. ferrugineus* at 90 and 70°F. and 90% R.H., but *C. ferrugineus* produced more at 90°F. and 70% R.H. These results would indicate that *C. ferrugineus* is less sensitive to a reduction in relative humidity than is *C. turcicus*.

CHAPTER VII

EFFECT OF MILL STOCKS ON THE RATE OF DEVELOPMENT AND SURVIVAL OF *C. turcicus* AND *C. ferrugineus* AT VARIOUS TEMPERATURES AND RELATIVE HUMIDITIES

Definition of terminology

The term mill stocks refers to the different physical structure and chemical composition of the partially ground wheat kernel as found in the various machinery of the mill. In this investigation, the mill stocks include three grades of the four commonly designated fractions of break, tailings, middlings and low grade.

Methods and materials

The effect of mill stocks on the rate of development and survival of *C. turcicus* was investigated in a series of experiments at a relative humidity of 90 per cent and at temperatures of 90, 80, 70 and 60°F. and of *C. turcicus* and *C. ferrugineus* at 90°F. and 70% R.H.

Cultures of one week old adults of each species were set up on flour which had been sieved through a 100 mesh to the inch sieve. The flour from the cultures was sifted daily and the eggs removed. In the series of experiments with *C. turcicus* at 90% R.H., ten, 0-24 hour old first instar larvae were reared individually in 5 ml. shell vials containing 0.5 grams of one of the 12 stocks. Beginning fifteen days after the larvae were placed on the food media, the vials, which were stored in desiccators, were examined daily until all living larvae had pupated and emerged as adults. These experiments were done in duplicate.

In the series of experiments with C. turcicus and C. ferrugineus at 70% R.H., duplicate lots of ten, 0-24 hour old first instar larvae of each species were set up as in the previous series. Daily examinations were begun ten days after the experiment was set up and continued until all living larvae had pupated and emerged as adults.

Results

The rate of development and per cent survival of C. turcicus on the different mill stocks at four temperatures and 90% R.H. are given in Tables VI through XIII and summarized in Table XIV. In general, there were more differences between milling fractions than between official grades.

At 90, 70 and 60°F. there was no significant difference in the rate of development between individuals on the three grades of any of the four milling fractions. At 80°F. there was a significant difference in the rate of development between individuals on the various grades of middlings and tailings.

At 90, 80 and 60°F. there was no significant differ-

TABLE VI

RATE OF DEVELOPMENT (DAYS) OF C. <u>turcicus</u> ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 90 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean'
Break	First	23.0	25.8	48.8	24.4
	Third	22.8	25.9	48.7	24.4
	Fifth	22.8	24.7	47.5	23.8
	Total	68.6	76.4	145.0	
Middlings	First	30.1	26.2	56.3	28.2
	Third	30.8	28.3	59.1	29.6
	Fifth	28.8	29.7	58.5	29.3
	Total	89.7	84.2	173.9	29.0
Tailings	First	23.1	27.0	50.1	25.1
	Fourth	23.0	22.0	45.0	22.5
	Germ	22.7	25.0	47.7	23.9
	Total	68.8	74.0	142.8	
Low grade	First	23.1	22.4	45.5	22.8
	Second	22.6	28.5	51.1	25.6
	Third	22.3	22.0	44.3	22.2
	Total	68.0	72.9	140.9	

' $LSD_{.05}$ not significant

TABLE VII

RATE OF DEVELOPMENT (DAYS) OF *C. turcicus* ON THREE GRADES OF FOUR MILLING FRACTIONS AT 80°F. AND 90 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean'
Break	First	34.0	34.5	68.5	34.3
	Third	34.6	34.6	69.2	34.6
	Fifth	34.2	33.6	67.8	33.9
	Total	102.8	102.7	205.5	34.3
	LSD.05				1.0
Middlings	First	40.0	39.3	79.3	39.7
	Third	36.9	37.8	74.7	37.4
	Fifth	40.4	40.7	80.7	40.4
	Total	116.9	117.8	234.7	39.1
	LSD.05				1.7
Tailings	First	34.4	35.0	69.4	34.7
	Fourth	32.1	34.5	66.6	33.3
	Germ	30.0	30.0	60.0	30.0
	Total	96.5	99.5	196.0	32.7
	LSD.05				3.2
Low grade	First	34.8	34.7	69.5	34.8
	Second	33.7	32.9	66.6	33.3
	Third	33.8	34.3	68.1	34.1
	Total	102.3	101.9	204.2	34.0
	LSD.05				1.5

TABLE VIII

RATE OF DEVELOPMENT (DAYS) OF C. *turcicus* ON THREE GRADES OF FOUR MILLING FRACTIONS AT 70°F. AND 90 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean'
Break	First	46.1	46.0	92.1	46.1
	Third	46.0	46.3	92.3	46.2
	Fifth	46.2	45.9	92.1	46.1
	Total	138.3	138.2	276.5	
Middlings	First	48.0	48.6	96.6	48.3
	Third	49.0	48.2	97.2	48.6
	Fifth	48.4	48.5	96.9	48.5
	Total	145.4	145.3	290.7	
Tailings	First	48.3	49.4	97.7	48.9
	Fourth	47.1	48.2	95.3	47.7
	Germ	45.9	45.7	91.6	45.8
	Total	141.3	143.3	284.6	
Low grade	First	46.6	46.2	92.8	46.4
	Second	45.9	45.1	91.0	45.5
	Third	46.5	45.8	92.3	46.2
	Total	139.0	137.1	276.1	

' LSD.05 not significant

TABLE IX

RATE OF DEVELOPMENT (DAYS) OF C. turcicus ON THREE GRADES OF FOUR MILLING FRACTIONS AT 60°F. AND 90 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean'
Break	First	104.0	106.2	210.2	105.1
	Third	100.4	103.7	204.1	102.1
	Fifth	102.0	104.1	206.1	103.1
	Total	306.4	314.0	620.4	
Middlings	First	108.7	106.9	215.6	107.8
	Third	113.0	105.7	218.7	109.4
	Fifth	104.1	106.3	210.4	105.2
	Total	325.8	318.9	644.7	
Tailings	First	99.0	101.8	200.8	100.4
	Fourth	95.8	97.1	192.9	96.5
	Germ	100.8	98.9	199.7	99.9
	Total	295.6	297.8	593.4	
Low grade	First	98.1	98.9	197.0	98.5
	Second	100.0	102.0	202.0	101.0
	Third	99.0	100.4	199.4	99.7
	Total	297.1	301.3	598.4	

' LSD.05 not significant

TABLE X

PER CENT SURVIVAL OF C. *turcicus* ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 90 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean'
Break	First	80.0	100.0	180.0	90.0
	Third	90.0	100.0	190.0	95.0
	Fifth	70.0	60.0	130.0	65.0
	Total	240.0	260.0	500.0	
Middlings	First	60.0	40.0	100.0	50.0
	Third	100.0	100.0	200.0	100.0
	Fifth	100.0	-	100.0	50.0
	Total	260.0	140.0	400.0	
Tailings	First	90.0	100.0	190.0	95.0
	Fourth	90.0	70.0	160.0	80.0
	Germ	90.0	90.0	180.0	90.0
	Total	270.0	260.0	530.0	
Low grade	First	90.0	100.0	190.0	95.0
	Second	100.0	40.0	140.0	70.0
	Third	70.0	100.0	170.0	85.0
	Total	260.0	240.0	500.0	

' LSD.05 not significant

TABLE XI

PER CENT SURVIVAL OF C. *turcicus* ON THREE GRADES OF FOUR MILLING FRACTIONS AT 80°F. AND 90 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean'
Break	First	60.0	70.0	130.0	65.0
	Third	50.0	50.0	100.0	50.0
	Fifth	90.0	90.0	180.0	90.0
	Total	200.0	210.0	410.0	
Middlings	First	40.0	40.0	80.0	40.0
	Third	40.0	30.0	70.0	35.0
	Fifth	40.0	40.0	80.0	40.0
	Total	120.0	110.0	230.0	
Tailings	First	70.0	80.0	150.0	75.0
	Fourth	80.0	70.0	150.0	75.0
	Germ	90.0	80.0	170.0	85.0
	Total	240.0	230.0	470.0	
Low grade	First	90.0	80.0	170.0	85.0
	Second	60.0	60.0	120.0	60.0
	Third	90.0	90.0	180.0	90.0
	Total	240.0	230.0	470.0	

' $LSD_{.05}$ not significant

TABLE XII

PER CENT SURVIVAL OF C. turcicus ON THREE GRADES OF FOUR MILLING FRACTIONS AT 70°F. AND 90 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate		Total	Mean
		1	2		
Break	First	80.0	80.0	160.0	80.0
	Third	100.0	90.0	190.0	95.0
	Fifth	50.0	60.0	110.0	55.0
	Total	230.0	230.0	460.0	76.7
	LSD.05				18.4
Middlings	First	80.0	90.0	170.0	85.0
	Third	60.0	70.0	130.0	65.0
	Fifth	100.0	90.0	190.0	95.0
	Total	240.0	250.0	490.0	81.7
	LSD.05				22.5
Tailings	First	70.0	70.0	140.0	70.0
	Fourth	70.0	80.0	150.0	75.0
	Germ	90.0	90.0	180.0	90.0
	Total	230.0	240.0	470.0	78.3
	LSD.05				22.5
Low grade	First	70.0	70.0	140.0	70.0
	Second	90.0	100.0	190.0	95.0
	Third	60.0	60.0	120.0	60.0
	Total	220.0	230.0	450.0	75.0
	LSD.05				39.0

TABLE XIII

PER CENT SURVIVAL OF C. turcicus ON THREE GRADES OF FOUR MILLING FRACTIONS AT 60°F. AND 90 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean'
Break	First	60.0	70.0	130.0	65.0
	Third	70.0	70.0	140.0	70.0
	Fifth	30.0	70.0	100.0	50.0
	Total	160.0	210.0	370.0	
Middlings	First	30.0	40.0	70.0	35.0
	Third	30.0	30.0	60.0	30.0
	Fifth	90.0	80.0	170.0	85.0
	Total	150.0	150.0	300.0	
Tailings	First	80.0	70.0	150.0	75.0
	Fourth	50.0	60.0	110.0	55.0
	Germ	40.0	50.0	90.0	45.0
	Total	170.0	180.0	350.0	
Low grade	First	70.0	70.0	140.0	70.0
	Second	90.0	90.0	180.0	90.0
	Third	50.0	60.0	110.0	55.0
	Total	210.0	220.0	430.0	

' LSD.05 not significant

TABLE XIV

MEAN RATE OF DEVELOPMENT (DAYS) AND PER CENT SURVIVAL OF *C. turcicus* ON FOUR MILLING FRACTIONS AT FOUR TEMPERATURES AND 90 PER CENT RELATIVE HUMIDITY

Fraction	90°F.		80°F.		70°F.		60°F.	
	Development	Survival	Development	Survival	Development	Survival	Development	Survival
Breaks	24.2	83.3	34.3	68.7	45.9	76.7	103.4	61.7
Middlings	29.0	66.7	39.1	38.3	48.5	81.7	107.5	48.3
Tailings	23.8	88.3	32.7	78.3	47.4	78.3	98.9	58.3
Low grades	23.5	83.3	34.0	75.0	46.0	76.7	99.7	71.7
LSD.05	2.6	47.3	0.8	21.5	0.7	6.3	2.6	12.9

ence between per cent survival on the three grades of the four milling fractions, but at 70°F. there was a significant difference between grades of breaks, middlings and low grades.

When the grades of each of the four fractions were averaged, there was no significant difference in the rate of development between breaks, tailings and low grades at 90°F., while at 80°F. development on tailings was significantly faster than on breaks or low grades, but there was no significant difference between the latter two. At 70°F. development was significantly faster on breaks and low grades than on tailings. At 60°F. development was significantly slower on breaks than on tailings and low grades. Development was significantly slower on middlings than on any other fraction at all four temperatures. The number of days required for development was increased by roughly 50 per cent for each ~~five~~ ten degree F. drop in temperature until 60°F. was reached where development time was double that required at 70°F.

Survival was not significantly affected by the type of food material at 90 or 70°F. although at 90°F. survival on middlings was 17 to 22 per cent lower than on the other three fractions. At 80°F. survival was fairly uniform on breaks, tailings and low grades but was significantly lower on middlings. At 60°F. there was no significant difference in survival on middlings or tailings but survival on middlings was significantly lower than on breaks or low grades.

The rate of development and per cent survival of *C. turcicus* at 90°F. and 70% R.H. are given in Tables XV and XVI, the same information for *C. ferrugineus* in Tables XVII and XVIII. A summary of the data for both species is given in Table XIX.

There was no significant difference in rate of development between grades or fractions for *C. turcicus*. It developed more rapidly at 90°F. and 70% R.H. than it did at any other combination of temperature and relative humidity tried. Survival of this species was significantly lower on middlings and tailings than on breaks and low grades.

At 90°F. and 70% R.H. the rate of development of *C. ferrugineus* was not altered by the various grades of the breaks or tailings, but a significant difference was observed between all three grades of middlings, the rate of development being increased as grade was lowered. Third low grade significantly lengthened the rate of development over that obtained for the other two grades of the fraction.

The rate of development of *C. ferrugineus* was more rapid than that of *C. turcicus* on breaks, tailings and low grades but equal on middlings. Development of *C. ferrugineus* was significantly slower on middlings than on the other three fractions. The latter three were equal in their effect on rate of development.

More *C. ferrugineus* than *C. turcicus* survived on midd-

TABLE XV

RATE OF DEVELOPMENT (DAYS) OF C. turcicus ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean[I]
Break	First	22.6	25.3	47.9	24.0
	Third	22.0	24.0	46.0	23.0
	Fifth	22.0	25.5	47.5	23.8
	Total	66.6	74.8	141.4	
Middlings	First	24.0	25.3	49.3	24.5
	Third	25.3	-	25.3	25.3
	Fifth	24.4	-	24.4	24.4
	Total	73.7	25.3	99.0	
Tailings	First	24.3	21.3	45.6	22.8
	Fourth	23.1	21.3	44.4	22.2
	Germ	21.9	21.2	43.1	21.6
	Total	69.3	63.8	133.1	
Low grade	First	22.6	22.7	45.3	22.7
	Second	21.9	24.0	45.9	23.0
	Third	22.5	23.1	45.6	22.8
	Total	67.0	69.8	136.8	

[I] LSD.05 not significant

TABLE XVI

PER CENT SURVIVAL OF C. *turcicus* ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean'
Break	First	90.0	60.0	150.0	75.0
	Third	100.0	60.0	160.0	80.0
	Fifth	50.0	70.0	120.0	60.0
	Total	240.0	190.0	430.0	
Middlings	First	80.0	10.0	90.0	45.0
	Third	70.0	-	70.0	35.0
	Fifth	100.0	-	100.0	50.0
	Total	250.0	10.0	260.0	
Tailings	First	70.0	-	70.0	35.0
	Fourth	70.0	10.0	80.0	40.0
	Germ	90.0	-	90.0	45.0
	Total	130.0	10.0	140.0	
Low grade	First	70.0	60.0	130.0	65.0
	Second	100.0	80.0	180.0	90.0
	Third	60.0	60.0	120.0	60.0
	Total	230.0	200.0	430.0	

' LSD.05 not significant

TABLE XVII

RATE OF DEVELOPMENT (DAYS) OF C. *ferrugineus* ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean
Break	First	20.0	18.7	38.7	19.7
	Third	19.4	19.5	38.9	19.5
	Fifth	19.3	19.0	38.3	19.2
	Total	58.7	57.2	115.9	19.4
	LSD.05				17.5
Middlings	First	27.6	27.8	55.4	27.7
	Third	25.0	25.1	50.1	25.1
	Fifth	22.0	21.7	43.7	21.9
	Total	74.6	74.6	149.2	24.9
	LSD.05				1.5
Tailings	First	19.1	20.3	39.4	19.7
	Fourth	20.0	21.8	41.8	20.9
	Germ	19.4	18.2	37.6	18.9
	Total	58.5	60.3	118.8	19.8
	LSD.05				3.2
Low grade	First	18.3	19.6	37.9	19.0
	Second	19.4	18.9	38.3	19.2
	Third	21.4	21.7	43.1	21.6
	Total	59.1	60.2	119.3	19.9
	LSD.05				1.9

TABLE XVIII

PER CENT SURVIVAL OF C. ferrugineus ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean[1]
Break	First	60.0	90.0	150.0	75.0
	Third	70.0	60.0	130.0	65.0
	Fifth	70.0	70.0	140.0	70.0
	Total	200.0	220.0	420.0	
Middlings	First	80.0	60.0	140.0	70.0
	Third	90.0	90.0	180.0	90.0
	Fifth	80.0	90.0	170.0	85.0
	Total	250.0	240.0	490.0	
Tailings	First	80.0	60.0	140.0	70.0
	Fourth	60.0	50.0	110.0	55.0
	Germ	70.0	50.0	120.0	60.0
	Total	210.0	160.0	370.0	
Low grade	First	70.0	80.0	150.0	75.0
	Second	80.0	80.0	160.0	80.0
	Third	90.0	100.0	190.0	95.0
	Total	240.0	260.0	500.0	

[1] $LSD_{.05}$ not significant

TABLE XIX

MEAN RATE OF DEVELOPMENT (DAYS) AND PER CENT SURVIVAL OF *C. turcicus* AND *C. ferrugineus* ON FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	*C. turcicus*		*C. ferrugineus*	
	Development	Survival	Development	Survival
Breaks	23.6	71.7	19.4	70.0
Middlings	24.7	43.3	24.9	81.7
Tailings	22.2	40.0	19.8	61.7
Low grades	22.8	71.7	19.9	80.0
LSD.05	11.1	52.2	0.8	13.1

lings, tailings and low grades while survival on the break fraction was about the same for both species.

Discussion

It may be possible to explain the rate of development and survival data on the basis of environment. For C. turcicus, 90°F. and 70% R.H. may be optimal, thus allowing some lattitude in the nutritional value of the food without affecting the rate of development and survival of the larva. However, when the environment becomes marginal, differences in nutritional value of the food would become more apparent.

The effect of food on rate of development of a number of stored products insects has been investigated. Smallman and Loschiavo (1952) found development of T. confusum Duval larvae at 80°F. was most rapid on tailings, followed by low grades, middlings and breaks in that order. They also reported no significant differences in survival of the insect on any milling fraction, but Oosthuizen (1945) found the survival of T. castaneum (Hbst.) to be lower on bran, middlings and flour than it was on germ and semolina. Cotton et al (1944) reported that the numbers of insects in sections of flour mills containing food of high nutritive value were from one and one half to three times as great as the numbers in other sections of the mill containing less nutritive food. Fraenkel and Blewett (1943) stated that some stored products pests did as well on National flour (85 per cent extraction) as on wholemeal flour, but that flour of lower extraction formed a less suitable diet. On the latter, the period of development was longer and mortality was increased. Rilett (1949) reported that germ was the best diet for C. ferrugineus, and although bran was considerably better than white flour the period of development was doubled.

Poorer development on flours which were below 85 per cent extraction was attributed by Fraenkel and Blewett (1943) to a deficiency of B complex vitamins, the percentage of which falls as the extraction rate is lowered (Andrews et al, 1942; Tepley et al, 1942; Thomas et al, 1942). Hinton (1944) stated that the scutellum fraction of the germ contains about 60 per cent of the total aneurin in the wheat kernel. Nicotinic acid is found in the germ and outer endosperm, with the highest concentration in the germ (Moran, 1945). He also stated that riboflavin is more uniformly distributed throughout the wheat grain than is nicotinic acid but the highest concentration is in the germ. As the extraction rate of flour falls, the germ is eliminated and increasing amounts of scutellum, bran and outer endosperm are excluded, resulting in the steady reduction of B group vitamins.

According to Williams (1954), Manitoba wheat and wholemeal flour were equally favorable for the development and survival of C. minutus followed by Plate maize and English wheat. National flour (85 per cent extraction) and Canadian flour (70-75 per cent extraction) were equally unfavorable. Ashby (1961) found that the rate of larval development of C. minutus was equal on wheat and on wholemeal flour plus ten per cent yeast.

Dyte (1961), working with samples from centrifugals (sifters) in flour mills in England concluded that moisture was by far the most important factor in determining where large populations of C. turcicus would build up, and nutritional value of the stock had little significance. Lefkovitch (1962) indicated that there may be selective feeding; particle size or type of food may affect rate of development and survival.

Considerable work has been done on the effect of food on the rate of development of Tribolium spp. Chapman (1924) stated that wheat germ more nearly satisfied the requirements for growth and transformation than did any other type of milling fraction. This was corroborated by Cashman (1951) and Sweetman and Palmer (1928) who reported that the wheat embryo seemed to contain some growth promoting substance, and when the embryo was not present, rate of growth was retarded.

Cotton et al (1945) showed that riboflavin did not significantly alter the rate of growth of T. confusum, but Mukerji and Sinha (1953) and Gray (1948) found that it did. Fraenkel and Blewett (1941) stated that riboflavin content of patent flour had the most marked effect of any of the B group vitamins on the growth rate of *T. confusum*. Mickel and Standish (1946, 1947) found that *T. confusum* and *T. castaneum* developed more rapidly on cereals than on soy products, indicating that the soy products were lacking in necessary amounts of some growth promoting substance or substances.

Investigations in flour mills by Miller (1944) showed that tailings favored more rapid development of larvae of *T. confusum* than patent flours, first break being only slightly less favorable than tailings. In a laboratory investigation with milling fractions, Smallman and Loschiavo (1952) found that rate of development of *T. confusum* was significantly slower on tailings than on breaks, middlings and low grades. There was no difference between the latter three.

Rate of development of Ptinid beetles was observed to be altered by type of food (Howe and Burges, 1952, 1953) and Richardson (1926) found that *Anagasta kühniella* (Zell.) developed more rapidly when the germ of the wheat kernel was included in the food supply. Thomas and Shepard (1940) observed that larvae of *Oryzaephilus surinamensis* (L.) developed faster on rolled oats than on walnuts or raisins. Rate of development of larvae of *T. destructor* Uytt. was correlated to the food the adult insect received (Reynolds, 1945), but this was thought to be due to the presence of intracellular symbionts which supplied vitamins, or that the nutritive value of the yolk of the egg was partly responsible for the acceleration in growth observed in the following generation (Cashman, 1950). Daily disturbance and a daily temperature drop of only 30 minutes duration was sufficient to significantly increase the length of the larval period of the Khapra beetle (Burges, ~~1961~~ 1957). Stanley (1946) showed that high temperature favors rapid development of certain insects but the number reaching the adult stage is reduced. At lower temperatures, slower development is associated with high survival.

The response of an insect is expressed in part by the measurable functions of rate of development and per cent survival. Within the range of optimum temperature and relative humidity, different foods may or may not affect the rate of development and per cent survival. If significant differences are found in these latter two criteria, then it must be assumed that the food is the factor causing the change. As temperature and moisture conditions become marginal any differences in rate of development and survival may be due to environmental conditions alone or in combination with food differences.

Several statistics have been devised in an effort to evaluate the effect of a combination of factors such as temperature, moisture, food, etc. on the rate of increase of the species. The method of Birch (1953) and the modification of Howe (1953) include a parameter denoted by the letter *r* and called the intrinsic or infinitesimal rate of increase. This parameter r may be calculated for any kind of life cycle, but applies only to a population with a stable age distribution. Howe (1953) stated "the main disadvantage of the method of Birch is that it involves the use of trial and error solutions of an equation, each involving the summation of values obtained from exponential tables". To simplify this method for those not mathematically inclined, Howe inserted a prerequisite: a female life table and an age-specific fecundity table; the life table giving the probability at birth (lx) of a female being alive at any stated age x, and the age-specific fecundity table giving the mean number of female offspring (mx) produced per unit of time by a female of age x. It is possible to deal with the developmental portion of the tables and the adult portion separately. In such a case, a figure for the mean developmental period is obtained from one experiment and the age-specific fecundity data from a second experiment using freshly emerged adults and recording the number of eggs laid throughout the oviposition period.

Birch (1953) stated "the innate capacity is defined as the intrinsic rate of increase r or its expression as a finite rate λ, where λ equals antilog r. This is the rate of increase of a population of stable age distribution growing in unlimited space at its optimum density". He found actual results of experimental models carried out under laboratory conditions to deviate somewhat from the theoretical calculations as variations in numbers occured, but the value of r was said to be real.

Analysis of the present results by the methods outlined above would require age-specific fecundity and life table data at each of the temperatures included in the experiments. All such data were not obtained, and as I was more concerned with results that might apply in practice rather than theoretical population increase, I chose to use the environmental index Er as outlined by Stanley (1946).

His calculations are validly based on the premise that optimum environmental conditions of temperature, relative humidity and food are not those at which the insect developed fastest, but those at which most was accomplished per unit of time in furthering the increase of the species. The relative environmental index is calculated by dividing the per cent survival of any one stage of the test animal by the time required to complete that stage. In this way a measure of the suitability of an environment is obtained, as it takes into account the rate of growth and mortality. If this value is determined for various temperatures or different foods, its highest value will be at the optimum temperature or on the preferred food. By expressing the relative values as a decimal fraction with the maximum equated to 1.0, an absolute environmental index Ea is obtained. This value will vary from 1.0 at the optimum to zero depending on the suitability of the environment in which the insect was reared. When these indices are applied to the results obtained in the present experiments it is possible to compare the nutritional value of the foods, as the temperature and relative humidity were standardized for all 12 foods.

Environmental indices for C. turcicus (Table XX) indicate that tailings and low grades were more favorable than the other fractions at all temperatures except 70°F. Most uniformity among fractions was shown at 70°F. followed by 60, 90 and 80°F. in descending order. The highest relative values were obtained at 90°F. indicating that this temperature at 90% R.H. was most favorable for the increase of the species followed by 80, 70 and 60°F. in descending order. This is different from the results obtained by Bishop (1959) and Lefkovitch (1962), who stated that the optimum for the species was below 90°F. Their results may have been adversely affected by the food medium and thus not truly representative of the rate of increase of C. turcicus.

According to the indices in Table XXI, there was more rapid development and greater survival of C. ferrugineus than C. turcicus at 90°F. and 70% R.H. By comparing relative indices in Table XX with those in Table XXI, it appears that 90°F. and 90% R.H. is the optimum for C. turcicus. Under actual mill conditions where the temperature of the stocks is close to 90°F. (Table II) and the moisture content is approx-

TABLE XX

ENVIRONMENTAL INDICES AS A MEASURE OF THE SUITABILITY OF FOUR MILLING FRACTIONS FOR DEVELOPMENT AND SURVIVAL OF *C. turcicus* AT FOUR TEMPERATURES AND 90 PER CENT RELATIVE HUMIDITY

Fraction	90°F.		80°F.		70°F.		60°F.	
	Index		Index		Index		Index	
	Relative	Absolute	Relative	Absolute	Relative	Absolute	Relative	Absolute
Breaks	3.22	0.87	1.94	0.79	1.67	0.99	0.52	0.73
Middlings	2.22	0.60	1.02	0.42	1.65	0.98	0.47	0.66
Tailings	3.64	0.98	2.45	1.00	1.62	0.96	0.71	1.00
Low grades	3.69	1.00	2.35	0.96	1.68	1.00	0.57	0.80

TABLE XXI

ENVIROMMENTAL INDICES AS A MEASURE OF THE SUITABILITY OF FOUR MILLING FRACTIONS FOR DEVELOPMENT AND SURVIVAL OF *C. turcicus* AND *C. ferrugineus* AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	*C. turcicus* Index		*C. ferrugineus* Index	
	Relative	Absolute	Relative	Absolute
Breaks	2.92	1.00	3.60	0.89
Middlings	1.13	0.39	3.29	0.82
Tailings	2.45	0.84	3.12	0.78
Low grades	2.04	0.70	4.02	1.00

imately equivalent to 70% R.H. or above in more than 50 per cent of the stocks (Table I), *C. turcicus* could be expected to present a serious threat as far as population level is concerned. This verifies what actually happens in practice.

By comparing the relative indices for *C. turcicus* and *C. ferrugineus* (Table XXI), it is apparent that 90°F. and 70% R.H. was more suitable to *C. ferrugineus* than *C. turcicus*. It would appear therefore, that heavy populations of *C. ferrugineus* could build up in milling machines if temperature, relative humidity and food were the only factors of importance concerning the rate of increase of the species. These data do not take into account the effect of interspecific competition or crowding, and we must also assume that *C. ferrugineus* is capable of gaining access to the milling machinery from the elevator section of the plant.

CHAPTER VIII

EFFECT OF MILL STOCKS ON THE RATE OF INCREASE OF *C. turcicus* AND *C. ferrugineus* IN THE LABORATORY

Methods and materials

Two experiments were conducted in the laboratory to give the following information:

1) Number of F_1 generation adults produced by *C. turcicus* under crowded conditions.

2) Number of offspring produced by one pair of adults of *C. turcicus* and *C. ferrugineus* in a 30 day period.

The number of F_1 generation adults of *C. turcicus* produced, and the mean time to produce them under crowded conditions on each of three grades of four milling fractions was determined by setting up 25 pairs of one week old adults on three grams of each food contained in 25 ml. shell vials. Duplicate vials were set up and the experiment was carried out in desiccators at 90°F. and 70% R.H. The original adults were removed to fresh food every 21 days to prevent newly emerged adults from laying eggs and adding to the total number of adults produced. After 63 days the original adults were removed and all vials were examined at two day intervals until all living larvae had pupated and emerged as adults.

The number of offspring produced by one pair of adults in a 30 day period on each of the 12 foods was determined for both species as follows:

One pair of one week old adults was placed in each of ten, 25 ml. shell vials containing three grams of one of the 12 foods. After 30 days the vials were examined and all living larvae, pupae and adults were counted. The experiment was run in duplicate and was carried out in desiccators maintained at 90°F. and 70% R.H.

Results

Great variability in the number of F_1 generation adults of C. turcicus produced and the mean time required to produce them was evident between fractions and grades. Significant differences in the number of adults formed were observed between all four fractions (Table XXII). The largest number was produced on tailings and the smallest number on middlings. This coincides with the survival data (Table XI). There were no differences in the mean number of days required to produce F_1 adults between breaks, tailings and low grades, but middlings was significantly poorer (Table XXIII). This coincides with the rate of development data (Table VII).

Significant differences in the number of F_1 adults formed were obtained between all three grades of breaks and tailings (Table XXIV). First low grade was significantly poorer than second or third low grade, the latter two being equal. No differences were observed between grades of middlings where few F_1 adults were formed.

TABLE XXII

NUMBER OF F_1 ADULTS PRODUCED ON THREE GRADES OF FOUR MILLING FRACTIONS BY 25 PAIRS OF ADULTS OF C. *turcicus* IN NINE WEEKS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean
Break	First	46	59	105	52.5
	Third	107	102	209	104.5
	Fifth	30	25	55	27.5
	Total	183	186	369	61.5
Middlings	First	27	25	52	26.0
	Third	24	28	52	26.0
	Fifth	31	34	65	32.5
	Total	82	87	169	28.2
Tailings	First	84	92	176	88.0
	Fourth	139	150	289	144.5
	Germ	202	220	422	211.0
	Total	425	462	887	147.8
Low grade	First	27	26	53	26.5
	Second	115	109	224	112.0
	Third	109	117	226	113.0
	Total	251	252	503	83.8
LSD.05					7.5

TABLE XXIII

NUMBER OF DAYS REQUIRED FOR F_1 GENERATION OF C. *turcicus* TO MATURE ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean
Break	First	39.3	40.2	79.5	39.8
	Third	41.9	42.6	84.5	42.3
	Fifth	46.0	45.4	91.4	45.7
	Total	127.2	128.2	255.4	42.6
Middlings	First	48.3	49.6	97.9	49.0
	Third	53.9	52.7	106.6	53.3
	Fifth	44.4	44.9	89.3	44.7
	Total	146.6	147.2	293.8	49.0
Tailings	First	50.8	46.2	97.0	48.5
	Fourth	39.5	40.5	80.0	40.0
	Germ	39.6	41.3	80.9	40.5
	Total	130.0	128.0	258.0	43.0
Low grade	First	47.7	44.8	92.5	46.3
	Second	40.4	41.4	81.5	40.8
	Third	37.3	37.5	74.8	37.4
	Total	125.4	123.4	248.8	41.5
LSD.05					1.6

TABLE XXIV

MEAN NUMBER OF F_1 ADULTS FORMED AND THE MEAN TIME REQUIRED TO PRODUCE THEM BY 25 PAIRS OF ADULTS OF C. turcicus IN NINE WEEKS ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction and grade	Number of F_1 adults formed	Mean time to produce F_1 (days)	Environmental index	
			Relative	Absolute
1st Break	52.5	39.8	1.3	0.25
3rd Break	104.5	42.3	2.5	0.48
5th Break	27.5	45.7	0.6	0.12
LSD.05	19.2	1.7	0.5	
1st Middlings	26.0	49.0	0.5	0.10
3rd Middlings	26.0	53.3	0.5	0.10
5th Middlings	32.5	44.7	0.7	0.13
LSD.05	6.9	2.4	0.2	
1st Tailings	88.0	48.5	1.8	0.35
4th Tailings	144.5	40.0	3.6	0.69
Germ tailings	211.0	40.5	5.2	1.00
LSD.05	29.3	6.5	0.6	
1st Low grade	26.5	46.3	0.6	0.12
2nd Low grade	112.0	40.8	2.7	0.52
3rd Low grade	113.0	37.4	3.0	0.58
LSD.05	13.0	3.8	0.3	

Significant differences in the mean number of days required to produce F_1 adults were obtained between all three grades of breaks and middlings, between first tailings and the other two tailings grades and between first low grade and the other two low grades. The latter two grades of tailings and low grades showed no respective differences.

Relative environmental indices were calculated by dividing the number of progeny produced by the time in days required to produce them (Table XXV). Significant differences in relative indices (Table XXIV) were obtained between all three grades of breaks and tailings and between first low grade and the other two low grades, the latter two of which were equal. No difference was obtained between grades of middlings as all three were equally poor. The mean environmental indices are grouped for fractions in Table XXVI. The results indicate tailings was the best fraction for the increase of *C. turcicus* and the other three fractions were significantly poorer. There were no differences between breaks and low grades, while middlings was the poorest.

Absolute indices (Tables XXIV, XXVI) were calculated by taking the highest relative value as an absolute value of 1.0 and this highest relative value was divided into each of the other relative values. The absolute values allowed a comparison between grades and fractions as to the value of the different foods for the increase of the species. Considerable

TABLE XXV

RELATIVE ENVIRONMENTAL INDICES AS A MEASURE OF SUITABILITY OF THREE GRADES OF FOUR MILLING FRACTIONS FOR PRODUCTION OF F_1 ADULTS OF *C. turcicus* AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	Replicate 2	Total	Mean
Break	First	1.17	1.47	2.64	1.32
	Third	2.55	2.39	4.94	2.47
	Fifth	0.65	0.55	1.20	0.60
	Total	4.37	4.41	8.78	1.46
Middlings	First	0.56	0.50	1.06	0.53
	Third	0.45	0.53	0.98	0.49
	Fifth	0.70	0.76	1.46	0.73
	Total	1.71	1.79	3.50	0.58
Tailings	First	1.65	1.99	3.64	1.82
	Fourth	3.51	3.70	7.21	3.61
	Germ	5.10	5.33	10.43	5.22
	Total	10.26	11.02	21.28	3.55
Low grade	First	0.57	0.58	1.15	0.58
	Second	2.85	2.65	5.50	2.75
	Third	2.92	3.12	6.04	3.02
	Total	6.34	6.35	12.69	2.12
LSD.05					1.30

TABLE XXVI

MEAN ENVIRONMENTAL INDICES AS A MEASURE OF SUITABILITY OF FOUR MILLING FRACTIONS FOR PRODUCTION OF F_1 ADULTS OF *C. turcicus* AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Number of F_1 adults formed	Mean time to produce F_1 (days)	Environmental index	
			Relative	Absolute
Breaks	61.5	42.6	1.5	0.44
Middlings	28.2	49.0	0.6	0.18
Tailings	147.8	43.0	3.6	1.00
Low grades	83.8	41.5	2.1	0.59
LSD.05	7.5	1.6	1.3	

variation in absolute indices were observed between grades of each fraction except middlings (Table XXIV). Germ tailings appeared to be the best for the increase of the species followed by fourth tailings, third low grade, second low grade and third break which were all about equal. Then came first tailings and first break and finally, fifth middlings, fifth break, first low grade, first middlings and third middlings which were all poor. Absolute indices (Table XXVI) indicate the suitability of the fractions for the increase of the species to be in the order of tailings, low grades, breaks and middlings. Tailings were roughly twice as beneficial for the increase of the species as breaks and low grades and five times as beneficial as middlings under crowded rearing conditions in the laboratory.

The number of offspring produced per female for each species in 30 days in the laboratory are listed for C. turcicus in Table XXVII and for C. ferrugineus in Table XXVIII.

On breaks, the number of offspring produced by C. turcicus decreased as grade was lowered. On middlings, tailings and low grades the numbers increased as grade was lowered, except on germ tailings which was poorer than the other two grades, but equal to first break. When grades of each fraction were averaged the number of offspring produced per female for C. turcicus was 8.8, 4.3, 42.0 and 29.1 for breaks, middlings, tailings and low grades, respectively. This agrees

TABLE XXVII

NUMBER OF OFFSPRING PRODUCED IN 30 DAYS BY ONE PAIR OF ADULTS OF C. <u>turcicus</u> ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Female	1st break	3rd break	5th break	1st middlings	3rd middlings	5th middlings	1st tailings	4th tailings	germ tailings	1st low grade	2nd low grade	3rd low grade
1	16	6	1	3	10	1	28	50	7	7	16	42
2	15	16	6	1	3	-	25	51	-	20	20	-
3	4	4	-	-	4	1	30	70	22	-	-	43
4	-	2	2	1	-	9	32	53	17	25	35	46
5	6	8	3	-	2	3	19	69	38	21	43	47
6	33	5	9	2	-	7	56	70	-	15	28	31
7	13	7	1	3	7	7	69	82	7	12	39	10
8	12	8	-	2	3	7	73	84	10	-	44	-
9	22	5	-	-	-	12	47	63	3	37	21	32
10	8	2	2	-	-	7	53	91	11	-	19	33
Mean	14.3	6.3	3.4	2.0	4.8	6.0	43.2	68.3	14.4	19.6	29.4	35.5
LSD.05 (fraction)		5.6			2.7			43.7			13.6	

TABLE XXVIII

NUMBER OF OFFSPRING PRODUCED IN 30 DAYS BY ONE PAIR OF ADULTS OF C. *ferrugineus* ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Female	1st break	3rd break	5th break	1st middlings	3rd middlings	5th middlings	1st tailings	4th tailings	germ tailings	1st low grade	2nd low grade	3rd low grade
1	7	38	6	5	10	2	7	16	30	28	38	20
2	20	24	12	6	10	18	13	11	52	26	25	23
3	7	32	10	12	12	16	16	6	45	30	28	12
4	16	18	22	14	11	13	7	9	44	23	23	18
5	9	29	15	17	14	15	13	29	21	27	47	17
6	10	33	17	9	18	21	7	17	32	13	23	10
7	11	27	34	16	12	18	11	21	46	18	19	14
8	13	13	25	13	10	14	13	18	34	11	14	11
9	9	19	14	11	8	10	11	19	56	17	18	10
10	12	19	20	23	11	17	17	13	58	15	14	10
Mean	11.4	25.2	17.5	12.6	11.6	14.4	11.5	15.9	41.8	20.8	24.9	14.5
LSD.05 (fraction)		14.0			9.3			16.6			15.6	

with previous experiments showing a decrease in suitability of the four fractions as food from tailings to low grades to breaks to middlings. An analysis of variance showed significant differences between fractions and grades. The tailings fraction was significantly better than the other three fractions for the production of offspring. Low grades were significantly better than breaks and middlings, the latter two being equal ($LSD_{.05}$ equal to 5.8). For grades, first break was significantly better than the other two grades which were equal. Fifth middlings was equal to third middlings, both of which were significantly better than first middlings. Fourth tailings was equal to first tailings but significantly better than germ tailings. Germ tailings and first tailings were equal. Third low grade was equal to second low grade and significantly better than first low grade, the latter two grades being equal.

For C. ferrugineus (Table XXVIII) there was no apparent pattern in the number of offspring produced on the different grades of the various fractions. When grades of each fraction were averaged, the number of offspring produced per female was 18.0, 12.9, 23.1 and 20.1 for breaks, middlings, tailings and low grades, respectively. These results are higher than those for C. turcicus on breaks and middlings and lower on tailings and low grades. The totals agree with previous experiments indicating a decrease in suitability of the four fractions from tailings to low grades to breaks to middlings for the production of offspring. An analysis of variance showed no significant differences between fractions (LSD .05 equals 13.9). Significant differences between grades were observed only on tailings where the germ tailings was significantly better than the other two grades.

Discussion

The calculated absolute indices increased as milling grade was lowered in the middlings, tailings and low grade fractions. As used in this thesis, the absolute index is a measure of the suitability of the environment for the increase of the species. As temperature and relative humidity were constant, the index values indicate that nutritional differences of the foods may have had an effect on the numbers produced. The amount of bran and germ chips in relation to endosperm increased as grade was lowered in each of the fractions mentioned above. The lowest of the absolute indices were obtained on middlings which is almost pure endosperm. The highest absolute index in the break fraction was obtained on the third grade, the first break being half this amount and the fifth break being half that of the first. This may be explained by the fact that although all the component parts of the wheat kernel are present in first break, the food consists of large chunks and in this form may not be readily available to the young larva. Third break is similar to first break in composition but the particle size is reduced in the third break probably making it easier for the young larva to feed. The fifth break consists almost entirely of bran and appears to be of much poorer nutritive value than the other two grades for the increase of the species.

Almost twice as many F_1 adults were produced on tailings as on low grades by C. turcicus, but the mean time to produce them was 1.5 days longer on tailings. Approximately 25 per cent fewer adults were produced and the number of days required to produce them was slightly longer on breaks than on low grades. The fewest adults were produced on middlings and it took almost a week longer for them to reach maturity than it did on the other three fractions. The ratio of number of progeny produced to the time required to produce them should provide a comprehensive index of the suitability of the milling fractions for the increase of C. turcicus as it takes into account the number of eggs laid, mortality of eggs and larvae and rate of larval development. It also includes the effects of interaction between the various stages such as cocoon damage by larvae.

On the basis of the absolute environmental indices the four milling fractions can be roughly divided into two groups: breaks and middlings on which rate of increase of C. turcicus was low, and tailings and low grades on which it was high. This coincides with the results obtained by Smallman and Loschiavo (1952) for T. confusum.

Significant differences were shown between grades with respect to both number of F_1 adults produced by C. turcicus and the mean number of days required to produce them. These results may be due to the unequal distribution of nutrients in the various grades of each fraction (Table I). Middlings are mostly endosperm with less protein than is present in the other fractions. First and third break contain all the essential parts of the whole kernel while the fifth break consists of almost pure bran. The removal of germ particles from the diet may be the reason for the poor rate of increase on this food. Although first and third break are similar chemically, the fact that third break consists of finer particles may make it easier for the insect to eat. This is reflected in rate of growth and reproduction.

The number of progeny produced by one pair of adults of each species in 30 days showed that for C. turcicus, the largest number of progeny was formed on tailings, the numbers being reduced on low grades, breaks and middlings in descending order. Compared with the 8.6 offspring per female of C. turcicus obtained by Bishop (1959) for the entire lifetime of the female, the present results are high. Bishop (1959) used equal parts of wholewheat flour and wheat germ as a food medium. The present results indicated poor production of progeny on germ tailings which is high in protein (Table I), although the present results of 14.4 progeny per female in a period of 30 days is almost double the figure reported by Bishop (1959).

The results obtained for *C. ferrugineus* indicated that this species showed less variation in number of progeny formed on the different foods than did *C. turcicus*. Most offspring of *C. ferrugineus* were produced on tailings; fewer were produced on low grades, breaks and middlings in descending order. This coincides with the results obtained with *C. turcicus*.

The number of insects in the various fractions in milling machines will be determined by the number of insects added to the fraction as well as by the suitability of the food for insect growth and reproduction. Willis and Roth (1950a, 1950b) demonstrated that attraction of *T. castaneum* to flour was affected by the moisture content of the flour, depending on whether the insects were starved or satiated they might be attracted or repelled by food of a high moisture content. Dyte (1961) stated that moisture content of the food appeared to be the most important factor in determining where large populations of *C. turcicus* would build up in mills. The present data tends to refute this belief as significant differences in the number of offspring produced were observed between foods when moisture content was held constant.

Insects can be introduced into a milling fraction by choice, by chance or by both (Loschiavo, 1959). In flour mills where the stocks are moved mainly by gravity, insect distribution may be by chance more so than by choice. Once the insects are present in a particular stock their rate of increase may be governed by nutritional value as well as the temperature and moisture content of the food.

CHAPTER IX

EFFECT OF MILL STOCKS ON OVIPOSITION OF *C. turcicus* AND *C. ferrugineus*

Methods and materials

Two experiments were conducted to determine the effect of food on egg production. The first was carried out in desiccators maintained at 90°F. and 90% R.H. One pair of one week old adults of *C. turcicus* which had not been allowed to mate were placed in each of five, two ounce salve tins containing one gram of one of the 12 stocks. Eggs and young larvae were removed weekly. The experiment was terminated at the end of seven weeks because egg laying became erratic. Dead males were replaced at each examination and females which did not lay eggs were discarded and replaced. Although a stereoscopic microscope was used, it is probable that egg counts were lower than actual since some of the eggs may have been missed, particularly in the coarser stocks.

The second experiment was conducted in the same way as the first, for each of *C. turcicus* and *C. ferrugineus*, except that the relative humidity was lowered to 70 per cent.

Results

The results for experiment one are presented in Table XXIX and summarized in Table XXX. There was no significant

TABLE XXIX

TOTAL NUMBER OF EGGS PER FEMALE OF C. *turcicus* ON THREE GRADES OF FOUR MILLING FRACTIONS IN SEVEN WEEKS AT 90°F. AND 90 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Replicate 1	2	3	4	5	Total	Mean
Break	First	90	87	67	71	67	382	76.4
	Third	53	51	54	60	51	269	53.8
	Fifth	87	109	81	151	138	566	113.2
	Total	230	247	202	282	256	1217	81.1
Middlings	First	8	--	--	--	--	8	1.6
	Third	--	1	15	--	--	16	3.2
	Fifth	65	86	79	6	--	236	47.2
	Total	73	87	94	6	--	260	17.3
Tailings	First	82	96	87	100	93	458	91.6
	Fourth	72	76	84	75	77	384	76.8
	Germ	51	43	37	40	38	209	41.8
	Total	205	215	208	215	208	1051	70.1
Low grade	First	76	111	82	93	88	450	90.0
	Second	175	100	125	91	136	627	125.4
	Third	30	37	--	--	75	142	28.4
	Total	281	248	207	184	299	1219	81.3

TABLE XXX

MEAN NUMBER OF EGGS PER FEMALE OF C. *turcicus* ON THREE GRADES OF FOUR MILLING FRACTIONS IN SEVEN WEEKS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Mean no. of eggs	Mean	LSD.05
Break	First	76.4		
	Third	53.8		
	Fifth	113.3		
	Mean		81.1	
	LSD.05	26.2		
Middlings	First	1.6		
	Third	3.2		
	Fifth	47.2		
	Mean		17.3	
	LSD.05	34.4		
Tailings	First	91.6		
	Fourth	76.8		
	Germ	41.8		
	Mean		70.1	
	LSD.05	8.1		
Low grade	First	90.0		
	Second	125.4		
	Third	28.4		
	Mean		81.3	
	LSD.05	37.7		
LSD.05				15.2

difference in the number of eggs laid between breaks, tailings or low grades, but significantly fewer eggs were laid on middlings. There was a significant difference in the number of eggs laid between each grade of tailings with fewer eggs being laid as the grade was lowered. More eggs were laid on fifth break and fifth middlings than on first and third break or first and third middlings in that order. Significantly fewer eggs were laid on third low grade than on first or second low grade. There was no difference between either first and third break or first and second low grade.

The results for experiment two are presented in Table XXXI for _C. turcicus_ and Table XXXII for _C. ferrugineus_. A summary for both species is given in Table XXXIII. _C. turcicus_ laid significantly fewer eggs at 90°F. and 70% R.H. on breaks and low grades than on tailings. Fewer eggs were laid on middlings than on any other fraction. The number of eggs laid by _C. turcicus_ on first break was significantly lower than that on either third or fifth break which were equal. Significantly fewer eggs were laid on fifth middlings than on first or third middlings. The latter two grades were equal. No significant differences were observed between grades of tailings, but significantly fewer eggs were laid on first and third low grades than on second low grade.

Bishop (1959) reported the lifetime average number of

TABLE XXXI

NUMBER OF EGGS PER FEMALE PER WEEK FOR C. turcicus ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Female	Week 1	2	3	4	5	6	7	Total	Mean
Break	First	1	0	8	11	5	6	8	2	40	
		2	9	13	12	6	8	11	7	66	
		3	0	8	2	5	5	4	1	25	
		4	7	7	2	7	9	6	3	41	
		5	5	8	3	13	6	1	2	38	
		6	0	9	3	4	4	7	2	29	
		7	7	7	5	5	11	6	5	46	
		8	2	10	11	5	5	4	2	39	
		9	0	4	14	9	7	6	3	43	
		10	0	9	10	4	8	8	5	44	
		Total	30	83	73	63	69	61	32	411	41.0
	Third	1	16	12	9	3	8	4	0	52	
		2	17	46	6	5	11	7	9	101	
		3	3	20	6	4	8	4	0	45	
		4	9	13	9	1	3	0	0	35	
		5	19	11	21	8	8	2	0	69	
		6	12	17	3	8	9	2	2	53	
		7	11	12	19	8	8	7	5	70	
		8	12	10	9	5	11	6	2	55	
		9	9	9	11	8	8	5	2	52	
		10	23	16	12	9	5	5	0	70	
		Total	131	166	105	59	79	42	20	602	60.2
	Fifth	1	23	27	16	11	12	9	5	103	
		2	10	19	6	2	0	1	0	38	
		3	0	8	21	12	7	6	4	58	
		4	14	21	10	2	10	6	0	63	
		5	9	27	19	9	0	2	4	70	
		6	28	19	17	16	10	8	7	105	
		7	12	24	14	13	7	8	2	80	
		8	19	22	6	4	2	1	1	55	
		9	16	17	11	4	6	6	2	62	
		10	9	18	24	8	3	2	4	68	
		Total	140	202	144	81	57	49	29	702	70.2

TABLE XXXI (Continued)

Fraction	Grade	Female	Week 1	2	3	4	5	6	7	Total	Mean
Middlings	First	1	13	8	1	0	2	1	0	25	
		2	2	3	4	0	18	6	2	35	
		3	3	23	0	7	0	0	0	33	
		4	10	13	1	0	0	0	0	24	
		5	4	8	7	2	0	0	0	21	
		6	5	5	13	4	8	5	1	41	
		7	2	4	2	0	5	2	1	16	
		8	0	4	9	11	4	1	0	29	
		9	3	7	5	2	6	6	2	31	
		10	4	12	2	3	1	0	1	23	
		Total	46	87	44	29	44	21	7	278	27.7
	Third	1	11	6	0	3	0	0	0	20	
		2	13	8	0	1	0	0	0	22	
		3	5	3	17	8	0	2	1	36	
		4	6	2	9	7	4	0	0	28	
		5	15	18	4	2	1	0	0	40	
		6	0	3	2	7	2	1	0	15	
		7	0	2	6	5	0	3	0	16	
		8	1	1	4	7	2	3	2	20	
		9	5	5	9	8	2	1	4	34	
		10	13	17	5	2	1	0	0	38	
		Total	69	65	56	50	12	10	7	269	26.9
	Fifth	1	0	2	6	5	0	3	0	16	
		2	0	4	3	8	10	0	0	25	
		3	1	13	1	4	0	0	0	19	
		4	0	6	10	5	2	0	0	23	
		5	2	2	4	3	8	2	1	22	
		6	0	1	7	3	3	4	2	20	
		7	0	0	2	2	1	3	1	9	
		8	1	2	7	8	3	3	0	24	
		9	3	3	0	2	4	1	2	15	
		10	2	1	3	4	4	2	1	17	
		Total	9	34	43	44	35	18	7	190	19.0

TABLE XXXI (Continued)

Fraction	Grade	Female	Week 1	2	3	4	5	6	7	Total	Mean
Tailings	First	1	8	39	4	12	13	6	1	83	
		2	17	12	6	0	2	0	1	38	
		3	25	47	15	17	17	13	9	143	
		4	13	15	5	2	8	1	2	46	
		5	0	33	5	23	37	22	6	126	
		6	5	28	16	18	13	9	7	96	
		7	5	39	7	9	7	8	2	77	
		8	10	29	13	10	4	6	12	84	
		9	8	24	6	11	13	9	7	78	
		10	15	23	17	16	16	10	6	103	
		Total	106	289	94	118	130	84	53	874	87.4
	Fourth	1	24	15	6	12	8	8	4	77	
		2	27	18	8	9	21	12	7	102	
		3	25	14	4	17	19	3	2	84	
		4	31	10	9	11	14	5	6	86	
		5	17	13	11	14	16	16	9	96	
		6	24	17	7	18	27	13	4	110	
		7	12	22	8	15	22	3	6	88	
		8	18	25	9	11	9	8	5	85	
		9	11	13	18	12	17	4	3	78	
		10	9	19	12	16	23	16	8	103	
		Total	198	166	92	135	176	88	54	909	90.9
	Germ	1	6	18	17	10	17	3	4	75	
		2	12	21	3	17	29	21	18	121	
		3	24	34	3	17	31	22	30	161	
		4	3	27	5	3	7	2	4	51	
		5	4	26	15	6	4	0	8	63	
		6	21	25	2	13	19	20	3	103	
		7	16	19	13	9	11	2	6	76	
		8	17	20	3	8	27	18	13	106	
		9	9	25	4	11	9	6	2	66	
		10	8	21	6	17	10	18	2	82	
		Total	120	236	71	111	164	112	90	904	90.4

TABLE XXXI (Continued)

Fraction	Grade	Female	Week 1	2	3	4	5	6	7	Total	Mean
Low grade	First	1	12	31	7	11	3	0	1	65	
		2	19	13	4	16	3	2	0	57	
		3	4	14	4	14	3	2	3	44	
		4	0	2	9	7	2	0	0	20	
		5	25	19	7	2	0	1	1	55	
		6	16	8	15	9	5	3	2	58	
		7	4	26	11	3	7	2	0	53	
		8	7	17	22	0	7	2	1	56	
		9	3	12	5	11	4	1	1	37	
		10	8	7	4	13	5	2	4	43	
		Total	98	149	88	86	39	15	13	488	48.8
	Second	1	15	31	11	3	17	0	18	95	
		2	12	17	22	3	4	7	1	66	
		3	19	26	11	18	4	1	1	80	
		4	21	18	0	9	0	1	0	49	
		5	36	22	2	9	0	3	0	72	
		6	24	19	0	11	14	8	3	79	
		7	13	23	9	7	0	2	3	57	
		8	16	12	24	7	4	3	2	68	
		9	15	27	17	8	11	3	9	90	
		10	22	14	3	7	7	4	2	59	
		Total	193	209	99	82	61	32	39	715	71.5
	Third	1	26	15	7	4	1	0	0	53	
		2	0	21	9	14	3	7	2	56	
		3	16	4	12	11	7	2	3	55	
		4	24	9	11	10	6	2	4	66	
		5	7	14	3	2	1	0	2	29	
		6	11	19	6	15	5	4	1	61	
		7	8	22	11	10	9	2	0	62	
		8	7	17	7	12	3	2	2	50	
		9	0	18	10	10	7	8	3	56	
		10	4	25	7	8	4	0	1	49	
		Total	103	164	83	96	46	27	18	537	53.7

TABLE XXXII

NUMBER OF EGGS PER FEMALE PER WEEK FOR C. *ferrugineus* ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Female	Week 1	2	3	4	5	6	7	Total	Mean
Break	First	1	5	6	4	11	8	12	20	66	
		2	10	12	14	16	16	14	13	95	
		3	6	9	14	18	20	19	12	98	
		4	6	9	9	6	4	9	17	60	
		5	10	17	14	16	11	12	27	107	
		6	9	14	9	9	8	12	16	77	
		7	10	21	9	6	10	11	11	78	
		8	4	15	2	5	12	6	9	53	
		9	23	6	12	11	17	8	15	92	
		10	7	7	18	13	10	12	7	74	
		Total	90	116	105	111	116	115	147	800	80.0
	Third	1	9	9	14	9	8	16	12	77	
		2	10	9	21	11	11	10	6	78	
		3	17	10	22	10	16	16	6	97	
		4	20	24	12	24	20	9	22	131	
		5	6	16	18	10	12	20	21	103	
		6	5	7	8	19	14	4	12	69	
		7	10	14	24	16	15	6	5	90	
		8	13	19	18	8	11	9	4	82	
		9	14	19	17	17	20	8	3	98	
		10	8	8	16	12	9	11	10	74	
		Total	112	135	170	136	136	109	101	899	89.9
	Fifth	1	11	10	5	4	15	3	8	56	
		2	13	19	13	10	8	9	15	87	
		3	15	15	15	15	16	16	27	119	
		4	10	15	12	12	8	10	7	74	
		5	14	20	6	4	8	11	22	85	
		6	13	19	18	12	6	7	10	85	
		7	9	12	3	8	15	4	5	56	
		8	14	27	16	15	16	16	13	117	
		9	17	14	10	18	21	8	3	91	
		10	12	8	13	9	3	7	2	54	
		Total	128	159	111	107	116	91	112	824	82.4

TABLE XXXII (Continued)

Fraction	Grade	Female	Week 1	2	3	4	5	6	7	Total	Mean
Middlings	First	1	3	3	1	3	0	0	1	11	
		2	7	5	4	4	0	1	0	21	
		3	3	1	0	1	0	0	0	5	
		4	10	17	6	3	2	1	0	39	
		5	4	8	2	7	4	3	1	29	
		6	1	6	4	5	3	1	0	20	
		7	7	14	10	5	2	2	0	40	
		8	2	9	9	9	3	4	2	38	
		9	7	2	3	6	5	2	1	26	
		10	5	6	5	5	8	7	3	39	
		Total	49	11	44	48	27	21	8	268	26.8
	Third	1	2	3	3	5	1	3	3	20	
		2	4	6	1	2	2	4	4	23	
		3	3	6	2	2	1	1	3	18	
		4	5	4	2	1	3	2	4	21	
		5	4	3	3	2	3	1	0	16	
		6	2	5	6	7	2	1	0	23	
		7	8	6	5	1	2	1	1	24	
		8	4	9	11	6	4	1	4	39	
		9	3	4	3	1	2	1	0	14	
		10	5	2	4	8	5	2	3	29	
		Total	40	48	40	35	25	17	22	227	22.7
	Fifth	1	5	5	2	4	4	3	1	24	
		2	12	13	6	7	5	5	22	70	
		3	7	8	4	10	22	19	20	90	
		4	4	6	22	15	8	0	2	57	
		5	3	2	18	5	4	7	2	41	
		6	3	3	11	24	9	11	6	67	
		7	7	2	3	12	16	13	8	61	
		8	4	7	13	15	11	5	8	63	
		9	6	17	15	8	4	2	0	52	
		10	9	13	7	7	4	2	1	43	
		Total	60	76	101	107	87	67	70	568	56.8

TABLE XXXII (Continued)

Fraction	Grade	Female	Week 1	2	3	4	5	6	7	Total	Mean
Tailings	First	1	12	16	11	11	10	12	26	98	
		2	8	8	9	10	14	7	5	61	
		3	20	21	24	26	14	14	24	143	
		4	7	8	15	16	19	20	20	105	
		5	9	10	5	4	6	7	14	55	
		6	8	17	21	7	14	8	5	80	
		7	1	3	5	20	4	10	7	50	
		8	6	3	4	18	13	11	10	65	
		9	7	12	11	10	8	9	11	68	
		10	12	16	18	15	12	8	5	86	
		Total	90	114	123	137	114	106	127	811	81.1
	Fourth	1	6	7	5	4	5	7	7	41	
		2	15	20	8	9	2	2	13	69	
		3	7	8	12	12	6	8	8	61	
		4	4	9	2	5	6	4	8	38	
		5	17	20	12	13	8	12	7	89	
		6	0	5	37	21	12	6	3	84	
		7	1	15	13	14	9	9	14	75	
		8	5	13	9	14	8	2	5	56	
		9	11	22	3	7	7	5	6	61	
		10	3	15	10	12	11	11	9	71	
		Total	69	134	111	111	74	66	80	645	64.5
	Germ	1	7	10	9	20	20	24	13	103	
		2	10	13	6	5	8	8	3	53	
		3	5	6	9	7	7	10	5	49	
		4	6	4	5	10	11	9	8	53	
		5	0	6	4	7	2	2	3	24	
		6	12	14	9	6	7	14	4	66	
		7	7	14	8	9	8	7	8	61	
		8	2	5	8	7	7	12	11	52	
		9	6	10	11	5	10	4	2	48	
		10	9	5	18	16	16	9	12	75	
		Total	64	87	77	92	96	99	69	584	58.4

TABLE XXXII (Continued)

Fraction	Grade	Female	Week 1	2	3	4	5	6	7	Total	Mean
Low grade	First	1	8	8	8	10	10	17	7	68	
		2	17	20	22	18	16	19	7	119	
		3	9	12	4	2	5	6	3	41	
		4	4	9	3	8	13	13	6	56	
		5	0	6	5	8	8	16	11	54	
		6	11	15	23	7	10	6	4	76	
		7	14	18	5	21	16	8	2	84	
		8	4	5	6	37	16	21	9	98	
		9	35	11	5	26	12	12	9	110	
		10	8	13	6	9	12	8	3	59	
		Total	110	117	87	146	118	126	61	765	76.5
	Second	1	14	20	6	7	20	23	11	101	
		2	12	24	10	15	20	17	10	108	
		3	13	14	4	3	8	8	7	57	
		4	5	3	8	20	11	11	2	60	
		5	10	13	6	9	9	20	3	70	
		6	8	12	5	8	7	7	6	53	
		7	2	16	2	5	14	0	3	42	
		8	5	8	18	19	13	14	12	89	
		9	5	5	7	16	22	14	12	81	
		10	12	15	24	19	11	21	8	110	
		Total	86	130	90	121	135	135	74	771	77.1
	Third	1	13	16	10	10	12	14	7	82	
		2	7	7	20	12	7	8	5	66	
		3	10	17	12	16	16	19	10	100	
		4	6	7	6	6	13	16	8	62	
		5	8	8	13	13	11	12	8	73	
		6	13	6	11	15	14	6	7	72	
		7	4	11	6	7	8	3	5	44	
		8	3	24	24	8	2	0	0	61	
		9	6	13	18	18	11	3	13	82	
		10	9	16	19	12	10	10	5	81	
		Total	79	125	139	117	104	91	68	723	72.3

TABLE XXXIII

MEAN NUMBER OF EGGS PER FEMALE FOR TEN FEMALES FOR SEVEN WEEKS FOR C. turcicus AND C. ferrugineus ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	C. turcicus		C. ferrugineus	
		Mean no. of eggs	LSD.05 fraction	Mean no. of eggs	LSD.05 fraction
Break	First	41.0		80.0	
	Third	60.2		89.9	
	Fifth	70.2		82.4	
	Mean	57.2	15.5	84.1	18.0
Middlings	First	27.7		26.8	
	Third	26.9		22.7	
	Fifth	19.0		56.8	
	Mean	24.5	6.8	35.4	12.2
Tailings	First	87.4		81.1	
	Fourth	90.9		64.5	
	Germ	90.4		58.4	
	Mean	89.6	24.6	72.1	20.1
Low grade	First	48.8		68.5	
	Second	71.5		77.1	
	Third	53.7		72.3	
	Mean	58.0	11.5	75.0	18.6
LSD.05		9.1		9.9	

eggs laid by C. turcicus to be lower than the seven week average obtained in the present study both at 90 and 70% R.H. These differences may be explained by nutritional differences in the food media.

C. ferrugineus laid more eggs than C. turcicus on all fractions except tailings (Table XXXIII), the mean of the four fractions being 65.0 eggs per female or 7.7 eggs per female more than C. turcicus. There was no significant difference in the number of eggs laid by C. ferrugineus on tailings or low grades, but there were fewer eggs laid on breaks. Egg production on middlings was significantly lower than on any other fraction.

There were no significant differences in the number of eggs laid by C. ferrugineus on various grades of breaks and low grades. Nor were there any differences between first and third grade middlings but there were fewer eggs laid on the fifth grade. Significantly fewer eggs were laid on germ tailings than on the first and fourth grades, the latter two being equal.

C. turcicus laid most eggs per female per week during the second week of the seven week oviposition period on each of the four fractions (Table XXXIV), the rate then falling steadily for the remainder of the experimental period. C. ferrugineus laid more eggs than C. turcicus except during the first two weeks and continued to lay at a fairly constant rate during the remainder of the seven week period (Table

TABLE XXXIV

MEAN NUMBER OF EGGS PER FEMALE PER WEEK FOR *C. turcicus* ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Week 1	2	3	4	5	6	7	Total	Mean
Break	First	3.0	8.3	7.4	6.2	6.9	6.1	3.2	41.1	
	Third	13.1	16.6	10.5	5.9	7.9	4.2	2.0	60.2	
	Fifth	14.0	20.2	14.4	8.1	5.7	4.9	2.9	70.2	
	Mean	10.0	15.0	10.8	6.7	6.8	5.1	2.7		57.2
Middlings	First	4.6	8.7	4.4	2.9	4.4	2.1	0.7	27.8	
	Third	6.9	6.5	5.6	5.0	1.2	1.0	0.7	26.9	
	Fifth	0.9	3.4	4.3	4.4	3.5	1.8	0.7	19.0	
	Mean	4.1	6.2	4.8	4.1	3.0	1.6	0.7		24.5
Tailings	First	10.6	28.9	9.4	11.8	13.0	8.4	5.3	87.4	
	Fourth	19.8	16.6	9.2	13.5	17.6	8.8	5.4	90.9	
	Germ	12.0	23.6	7.1	11.1	16.4	11.2	9.0	90.4	
	Mean	14.1	23.0	8.6	12.1	15.7	9.5	6.6		89.6
Low grade	First	9.8	14.9	8.8	8.6	3.9	1.5	1.3	48.8	
	Second	19.3	20.9	9.9	8.2	6.1	3.2	3.9	71.5	
	Third	10.3	16.4	8.3	9.6	4.6	2.7	1.8	53.7	
	Mean	13.1	17.4	9.0	8.8	4.9	2.5	2.3		58.0

XXXV). C. ferrugineus laid more eggs than did C. turcicus on a per female basis in the seven week period and C. ferrugineus continued to lay beyond this period. C. turcicus laid most eggs on tailings, while C. ferrugineus laid most eggs on breaks. Both species laid significantly fewer eggs on middlings than on the other fractions.

Discussion

The number of eggs laid by C. turcicus and C. ferrugineus are affected by the quality of the food available to the adult females. This disagrees with the work of Dyte (1961) who stated "it appears that numbers of C. turcicus are directly dependent on time and moisture content but that different levels of nutritional value make no detectable contribution to these numbers". At 90°F. and 70% R.H., C. ferrugineus laid more eggs per female than did C. turcicus. This agrees with the work of Bishop (1959) except that his figures for egg production are low. He recorded the lifetime average number of eggs per female of C. turcicus and C. ferrugineus to be 6.6 and 34.5 respectively, whereas, in the present study, under the same conditions of temperature and relative humidity, a seven week total of 57.3 and 65.0 eggs per female was recorded. In preliminary tests on oviposition in the laboratory it was observed that significantly fewer eggs were laid when the females were caged in 5 ml. shell vials than when they were caged in two

TABLE XXXV

MEAN NUMBER OF EGGS PER FEMALE PER WEEK FOR C. *ferrugineus* ON THREE GRADES OF FOUR MILLING FRACTIONS AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Fraction	Grade	Week 1	2	3	4	5	6	7	Total	Mean
Break	First	9.0	11.6	10.5	11.1	11.6	11.5	14.7	80.0	
	Third	11.2	13.5	17.0	13.6	13.6	10.9	10.1	89.9	
	Fifth	12.8	15.9	11.1	10.7	11.6	9.1	11.2	82.4	
	Mean	11.0	13.7	12.9	11.8	12.3	10.5	12.0		84.1
Middlings	First	4.9	7.1	4.4	4.8	2.7	2.1	0.8	26.8	
	Third	4.0	4.8	4.0	3.5	2.5	1.7	2.2	22.7	
	Fifth	6.0	7.6	10.1	10.7	8.7	6.7	7.0	56.8	
	Mean	5.0	6.5	6.2	6.3	4.6	3.5	3.3		35.4
Tailings	First	9.0	11.4	12.3	13.7	11.4	10.6	12.7	81.1	
	Fourth	6.9	13.4	11.1	11.1	7.4	6.6	8.0	64.5	
	Germ	6.4	8.7	7.7	9.2	9.6	9.9	6.9	58.4	
	Mean	7.4	11.2	10.4	11.3	9.5	9.0	9.2		68.0
Low grade	First	8.0	11.7	8.7	9.6	10.8	12.6	6.1	67.5	
	Second	8.6	13.0	9.0	12.1	13.5	13.5	7.4	77.1	
	Third	7.9	12.5	13.9	11.7	10.4	9.1	6.8	72.3	
	Mean	8.2	12.4	10.5	11.1	11.6	11.7	6.8		72.3

ounce salve tins although there was an equal food supply. The difference in the number of eggs laid may have been due to surface area. Bishop (1959) did not specify the size of the cage used to hold insects in his oviposition experiments. Cage size therefore, may have resulted in an under estimation of egg production by Bishop (1959).

During this investigation, no egg cannibalism by either species was observed. Shepard (1936), Rilett (1949) and Bishop (1959) all reported C. ferrugineus to eat its own eggs. If egg cannibalism was a factor in the present experiments, egg counts would be lower than actual. It is reasonable to assume that a species with cannibalistic tendencies would be most abundant in a food which was adequate nutritionally and in which the insect could best protect itself from cannibalism. This assumption is substantiated by the data which show the highest number of eggs were present in the break fraction. This is the coarsest food material included in the experiment, there being numerous cracks and crevices where eggs could be deposited and be protected from cannibalism (Figure 9).

Smith (1962) studied the rate of oviposition of C. ferrugineus on wholemeal flour and reported 7.27 eggs per female per day over a 30 day period at 88°F. and 70% R.H. For the first 30 days of the present investigation, C. ferrugineus females laid an average of 9.7 eggs per female per

Figure 9. Particles of first break stock showing cracks and crevices in which eggs and larvae of C. ferrugineus may hide and escape from cannibalism.

day at 90°F. and 70% R.H. The increase of almost 2.5 eggs per female per day may have been due to a combination of particle size of the food, slightly higher temperature and nutritive value of the food. In a period of 23 days, Rilett (1949) found the rate of oviposition of C. ferrugineus on whole wheat to be 2.54 eggs per female per day. This is considerably lower than the results obtained by Smith (1962) or in the present investigation, and it may have resulted from the fact that Rilett (1949) did not remove eggs or young larvae but waited for adults to mature and emerge. This may have resulted in a distorted picture of oviposition due to mortality, particularly if C. ferrugineus is cannibalistic. It is also possible that Rilett's results (1949) were due to the food on which the adults were reared. Present results indicate that food will alter the number of eggs laid. This indeed is an important factor not included in investigations by Rilett (1949) and Smith (1962).

Lefkovitch (1962) reared C. turcicus on wheatfeed and recorded 8.7 eggs per female per week for the first seven weeks of the 12 weeks he studied oviposition at 90°F. and 90% R.H. This compares favorably with the results obtained in this study showing an average of 8.9 eggs per female per week at 90°F. and 90% R.H. The increased rate of oviposition recorded for the present study on breaks, tailings and low grades and the depressed rate on middlings may be explained on the basis of nutritional value of the food. The food media used by Lefkovitch (1962) consisted of bran and endosperm which is a less nutritive food, as suggested by chemical analysis (Table I) than the break, tailings or low grade fractions.

On the basis of egg production, C. ferrugineus could possibly become more numerous than C. turcicus in milling machines. This does not take into account such factors as interspecific competition or cannibalism, but it is certainly reason to suspect that C. ferrugineus could become a pest in flour mills if it could overcome the mechanical barriers such as cleaning of the wheat and scouring with water, which tend to keep the insect out of the mill even though it may come into the elevator portion of the plant with the wheat supply.

Crombie (1942, 1944), Boyce (1946), MacLagen (1932), Richards (1947) and Park (1933) reported that insufficient food had a depressing effect on egg production. This factor could not exert itself in the present investigations as only one pair of adults was placed in each cage with an excess of food. Lefkovitch (1957) claimed that changing the food for oviposition experiments could depress or increase the rate of egg laying or delay the onset of oviposition and so not give a true picture. In the present experiments, it was felt that enough food was present to prevent appreciable contamination of the food with the resulting effect of decreased oviposition (Park and Lloyd, 1955).

Larson and Fisher (1924) found that feeding Bruchus *quadrimaculatus* Fab. substantially increased oviposition. Blake (1961) observed that the presence of food did not significantly increase oviposition by *Anthrenus verbasci* (L.). The present results lend support to the data gathered by Larson and Fisher (1924) which showed that food did affect oviposition, and are contradictory to the results of Blake, (1961), Dyte (1961) and Lefkovitch (1962b), all of whom claimed that food had little or no effect on the rate or increase in numbers of insects.

CHAPTER X

EFFECT OF FOOD PARTICLE SIZE ON OVIPOSITION BY *C. turcicus* AND *C. ferrugineus*

Methods and materials

Effect of food particle size on oviposition by *C. turcicus* and *C. ferrugineus* was determined using first break stock as the food medium. Duplicate lots of ten, two ounce salve tins each containing one gram of the food material and one pair of one week old adults of either species which had not previously been allowed to mate were set up. In half of the tins the food consisted of particles of first break stock sufficiently large to be retained by a 10 mesh to the inch sieve. In the other half of the tins the food was first break stock which had been ground in a Wiley Mill sufficiently fine to pass through a 30 mesh to the inch sieve. The tins were stored in desiccators at 90°F. and 70% R.H. for a period of seven weeks. Each week the eggs and larvae were removed.

Results

significantly fewer eggs were laid by *C. turcicus* on coarse food than on fine food (Table XXXVI) but there was no preference for a particular particle size by *C. ferrugineus* (Table XXXVII). The mean number of eggs per female per week for both species on coarse and fine food (Table XXXVIII)

TABLE XXXVI

EFFECT OF FOOD PARTICLE SIZE ON THE NUMBER OF EGGS PER FEMALE PER WEEK FOR *C. turcicus* AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Food	Female	Rep.	Week 1	2	3	4	5	6	7	Total
Coarse	1	1	0	8	7	6	6	4	2	33
	2		0	12	17	10	6	4	1	50
	3		0	8	9	10	7	5	3	42
	4		-	-	-	-	-	-	-	--
	5		1	9	12	5	4	2	3	36
	6		2	12	8	7	4	2	2	37
	7		0	9	7	4	1	1	0	22
	8		0	5	15	11	7	5	2	45
	9		-	-	-	-	-	-	-	--
	10		0	23	12	10	4	3	2	54
	Total		3	86	87	63	39	26	15	319
	1	2	0	5	7	2	2	2	1	19
	2		0	10	13	5	4	1	0	33
	3		-	-	-	-	-	-	-	--
	4		6	19	7	5	3	3	2	45
	5		1	18	7	10	3	2	0	41
	6		0	12	7	6	2	2	1	30
	7		-	-	-	-	-	-	-	--
	8		3	16	11	10	0	1	1	42
	9		0	10	4	9	3	1	2	29
	10		0	6	1	4	3	2	2	18
	Total		10	96	57	51	20	14	9	257

TABLE XXXVI (Continued)

Food	Female	Rep.	Week 1	2	3	4	5	6	7	Total
Fine	1	1	19	50	13	21	7	9	6	125
	2		25	43	21	4	3	1	0	97
	3		26	30	9	7	2	0	0	74
	4		22	37	20	4	2	3	3	91
	5		-	-	-	-	-	-	-	--
	6		31	31	29	12	4	9	7	123
	7		41	17	16	12	11	8	6	111
	8		-	-	-	-	-	-	-	--
	9		60	50	28	46	26	20	9	239
	10		35	42	11	6	0	3	0	97
	Total		259	300	147	112	55	53	31	957
	1	2	33	42	30	19	6	4	2	136
	2		-	-	-	-	-	-	-	--
	3		3	11	2	3	0	0	0	19
	4		20	8	5	2	7	5	3	50
	5		23	28	21	12	6	6	4	100
	6		25	35	28	10	7	4	3	112
	7		29	32	7	10	3	4	2	87
	8		23	46	17	5	1	6	1	99
	9		43	71	25	20	9	9	11	188
	10		8	9	23	25	11	5	0	81
	Total		207	282	158	106	50	43	26	872

TABLE XXXVII

EFFECT OF FOOD PARTICLE SIZE ON THE NUMBER OF EGGS PER FEMALE PER WEEK FOR C. ferrugineus AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Food	Female	Rep.	Week 1	2	3	4	5	6	7	Total
Coarse	1	1	12	-	-	-	-	-	-	12
	2		7	11	12	17	9	10	8	74
	3		7	10	11	18	21	16	11	94
	4		14	1	1	-	-	-	-	16
	5		9	8	13	4	1	-	-	35
	6		9	9	4	21	11	8	8	70
	7		10	13	7	14	11	11	2	68
	8		13	-	-	-	-	-	-	13
	9		7	8	12	20	13	8	3	71
	10		5	9	12	15	11	2	0	54
	Total		93	69	72	109	77	55	32	507
	1	2	1	9	14	7	16	-	-	47
	2		3	13	8	-	-	-	-	24
	3		3	19	23	16	6	12	15	94
	4		1	6	9	11	12	13	7	59
	5		2	15	37	21	16	7	5	103
	6		-	-	-	-	-	-	-	--
	7		4	8	15	20	8	8	3	66
	8		3	11	15	14	8	9	3	63
	9		-	-	-	-	-	-	-	--
	10		4	15	14	11	23	14	10	91
	Total		21	96	135	100	89	63	43	547

TABLE XXXVII (Continued)

Food	Female	Rep.	Week 1	2	3	4	5	6	7	Total
Fine	1	1	10	21	13	13	-	-	-	57
	2		8	34	13	14	13	16	17	115
	3		6	1	-	-	-	-	-	7
	4		10	17	20	16	16	20	18	117
	5		1	-	-	-	-	-	-	1
	6		10	8	21	12	18	12	6	87
	7		5	18	6	6	11	14	10	70
	8		-	-	-	-	-	-	-	--
	9		-	-	-	-	-	-	-	--
	10		5	4	-	-	-	-	-	9
	Total		55	103	73	61	58	62	51	463
	1	2	0	32	22	22	10	2	7	95
	2		1	16	15	17	3	2	8	62
	3		3	34	23	14	3	5	2	84
	4		0	21	12	19	16	18	16	102
	5		5	5	4	-	-	-	-	14
	6		1	25	14	8	8	2	12	70
	7		5	16	16	6	11	11	15	80
	8		0	21	15	15	12	13	8	84
	9		2	10	18	21	19	12	19	101
	10		1	13	11	-	-	-	-	25
	Total		18	193	150	122	82	65	87	717

TABLE XXXVIII

MEAN NUMBER OF EGGS PER FEMALE PER WEEK FOR SEVEN WEEKS ON COARSE AND FINE FOOD FOR *C. turcicus* AND *C. ferrugineus* AT 90°F. AND 70 PER CENT RELATIVE HUMIDITY

Week	*C. turcicus*'		*C. ferrugineus*''	
	Coarse food	Fine food	Coarse food	Fine food
1	0.8	27.4	6.3	1.7
2	11.4	34.2	10.3	17.4
3	9.0	17.9	12.9	14.9
4	7.1	12.8	14.9	14.0
5	3.7	6.2	11.9	11.7
6	2.5	5.6	9.8	11.4
7	1.5	3.4	6.3	11.5
Total	36.0	107.6	58.6	65.6
Mean	5.1	15.4	8.4	9.4

'F equals 32.0; F.01 equals 7.53

''F equals 0.38; F.05 equals 4.13

shows that *C. turcicus* laid most eggs in the second week and oviposition declined steadily from then on until the end of the experimental period. During the first week, *C. turcicus* laid very few eggs on coarse food and many on fine food. From the third to the seventh week, roughly twice as many eggs were laid on fine food as on coarse food. In the first week of oviposition, *C. ferrugineus* laid relatively few eggs on coarse food and very few on fine food. By the second week, egg production on fine food had almost doubled that on coarse food, but from the third to the seventh week the number of eggs laid was about equal on both types of food. *C. ferrugineus* maintained a fairly constant rate of egg production from week to week with almost as many eggs being laid per female in the seventh week as in each of the previous four or five weeks.

Discussion

Food particle size did not affect the number of eggs laid per female per week by *C. ferrugineus*, but *C. turcicus* laid significantly fewer eggs on coarse food.

Previous experimental work has indicated that nutritional differences of food will alter the egg laying capacity of *C. turcicus* and *C. ferrugineus*. To reduce the nutritional effect as much as possible in this experiment, the first break stock was used. This stock contains all the components of the wheat kernel, and when part of the food was ground in the Wiley Mill, extreme care was exercised to see that all the stock passed through the machine. This was done so the chemical composition of the finely ground food had not been altered. The fact that food particle size did affect egg production of C. turcicus and did not affect that of C. ferrugineus may be explained on the basis of the environment in which each species is usually found in Canada. C. turcicus is usually associated with mill stocks where the wheat kernel has been partly or completely ground up; C. ferrugineus is usually associated with whole grain and is, therefore, adapted to lay its eggs on coarse material. Both species have been reared on whole wheat in the laboratory. C. turcicus increased four-fold and C. ferrugineus increased twenty-fold in a period of 60 days.

If small larvae had not been removed each week during the current study it is assumed that a larger population of C. ferrugineus would have built up on the coarse food than on the fine food as the larvae might have found crevices in the coarse food in which they could hide and escape from cannibalism. The rapid increase of this insect in whole grain may be due to some extent to the protection afforded the larva by their habit of burrowing behind the germ of the kernel.

Food particle size affects rate of development of Ptinid beetles (Howe, 1949; Howe and Burges, 1953), T. confusum (Gray,

(1948) and *T. granarium* Everts. (Hopkins, 1955).

The data presented in this investigation support the data previously presented that egg laying by *C. ferrugineus* is maintained at a fairly constant rate over a period of seven weeks, while egg laying by *C. turcicus* gradually diminishes over the same period of time. The larger egg production by *C. turcicus* in this study is contrary to the previous chapter where it was found that *C. ferrugineus* laid more eggs on the break fraction than did *C. turcicus*. The reason for this difference may be due to the fact that on fine food, *C. turcicus* may have laid more eggs than it would have done on a mixture of coarse and fine particles, which is the type of food used in the previous experiment. The data show that *C. ferrugineus* is able to oviposit equally well in both coarse and fine foods, indicating that oviposition of this insect should not be affected by the particle size of any of the milling fractions.

CHAPTER XI

EFFECT OF MILL STOCKS ON RATE OF INCREASE OF *C. turcicus* AND *C. ferrugineus* IN MILLING MACHINES

Methods and materials

Twelve roll stands, each grinding one of the three grades of the four milling fractions used as food in previous experiments were selected in a flour mill in Winnipeg. In each of the 12 rolls were placed two, three ounce salve tins filled with the stock being ground by that particular set of rolls. One set of tins contained two pairs of one week old adults of *C. turcicus*, the other set, two pairs of one week old adults of *C. ferrugineus*. The tins were sealed with tape and suspended below the rolls within the roll housing by means of short lengths of wire. The salve tins were removed every 30 days and new ones were added. This continued for eight months. At the end of the eighth month, two sets of tins, each set containing 20 pairs of one week old adults of *C. turcicus* or *C. ferrugineus* and the appropriate food were placed in the machines and allowed to remain there for 30 days. Each time a set of tins was removed from the mill they were returned to the laboratory where all larvae, pupae, and adults were counted.

Results

Considerable variation in the number of offspring produced each month was evident for C. turcicus (Table XXXIX) and C. ferrugineus (Table XXXX). C. turcicus produced roughly half as many offspring in the eight months as did C. ferrugineus. C. turcicus increased most rapidly on breaks followed by middlings, low grades and tailings, even though complete mortality was observed in each food from time to time due to mold growth in the sealed tins. Middlings was the most suitable fraction for the increase of C. ferrugineus followed by tailings and then low grades. The species increased the least on breaks, possibly because of the competition from mold for the oxygen supply in the sealed containers.

In 30 days, the 20 pairs of adults of C. turcicus and C. ferrugineus produced roughly the same number of offspring per pair of adults (Table XXXXI) as did two pairs when the eight month totals for production of offspring were averaged. Table XXXXI corroborates the data in Tables XXXIX and XXXX showing that approximately twice as many offspring of C. ferrugineus as C. turcicus were formed. Only a small percentage of the C. turcicus larvae and approximately one third of the C. ferrugineus larvae were dead at the end of the 30 day period. The presence of a large number of cocoons and some F_1 adults in the C. turcicus series, and only a few pupae and no F_1 adults in the C. ferrugineus series, indicated that C. turcicus developed more rapidly under crowded conditions in milling machines than did C. ferrugineus.

TABLE XXXIX

NUMBER OF OFFSPRING PRODUCED EACH MONTH FOR EIGHT MONTHS IN FLOUR MILL ROLL STANDS BY TWO PAIRS OF ADULTS OF *C. turcicus* ON THREE GRADES OF FOUR MILLING FRACTIONS

Roll stand	Month of test								Total	Mean
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.		
First break	65	57	64	24	71	-	118	187	586	73.3
Third break	119	78	49	12	-	-	-	4	262	32.8
Fifth break	-	128	38	51	51	-	107	131	506	63.3
Total	184	263	151	87	122	-	225	322	1354	
First middlings	-	57	-	52	14	59	26	43	251	31.4
Third middlings	-	28	45	11	6	45	58	36	229	28.6
Fifth middlings	4	31	4	10	49	13	-	-	111	13.9
Total	4	116	49	73	69	117	84	79	591	
First tailings	-	-	-	15	6	-	-	-	21	2.6
Fourth tailings	-	2	7	21	6	5	57	-	98	12.5
Germ tailings	15	18	2	40	27	5	36	13	156	19.5
Total	15	20	9	76	39	10	93	13	275	
First low grade	-	3	17	44	2	20	24	-	110	13.8
Second low grade	-	-	-	-	-	-	-	-	-	-
Third low grade	-	2	2	18	115	73	31	-	241	30.1
Total	-	5	19	62	117	93	55	-	351	

TABLE XXXX

NUMBER OF OFFSPRING PRODUCED EACH MONTH FOR EIGHT MONTHS IN FLOUR MILL ROLL STANDS BY TWO PAIRS OF ADULTS OF C. ferrugineus ON THREE GRADES OF FOUR MILLING FRACTIONS

Roll stand	Month of test								Total	Mean
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.		
First break	29	80	-	10	62	-	-	15	196	24.5
Third break	4	97	80	-	-	-	-	77	258	32.3
Fifth break	-	74	1	102	91	9	144	0	421	52.6
Total	33	261	81	112	153	9	144	92	875	
First middlings	46	115	-	67	162	34	54	43	521	65.1
Third middlings	-	42	-	38	56	74	64	71	345	43.1
Fifth middlings	54	56	17	66	160	43	73	-	469	58.6
Total	100	213	17	171	378	151	191	114	1335	
First tailings	47	73	38	77	61	-	52	-	348	43.5
Fourth tailings	34	70	54	71	102	20	64	42	457	57.1
Germ tailings	43	42	-	90	43	34	44	36	332	41.5
Total	124	185	92	238	206	54	160	78	1137	
First low grade	67	67	-	60	156	9	92	-	451	56.8
Second low grade	48	28	18	61	36	21	50	-	262	32.8
Third low grade	-	48	7	44	129	81	63	-	372	46.5
Total	115	143	25	165	321	111	245	-	1085	

TABLE XXXXI

NUMBER OF OFFSPRING PRODUCED IN 30 DAYS IN FLOUR MILL ROLL STANDS BY 20 PAIRS OF ADULTS OF *C. turcicus* AND *C. ferrugineus* ON THREE GRADES OF FOUR MILLING FRACTIONS

Fraction	Grade	C. turcicus					C. ferrugineus				
		Larvae					Larvae				
		Live	Dead	Pupae	Adults	Tot.	Live	Dead	Pupae	Adults	Tot.
Break	First	239	1	38	36	314	60	102	0	0	162
	Third	144	3	74	0	221	0	0	0	0	0
	Fifth	159	6	40	0	205	130	12	0	0	142
	Total	542	10	152	36	740	190	114	0	0	304
Middlings	First	163	17	11	0	191	349	61	0	0	410
	Third	223	33	4	0	260	152	54	1	0	207
	Fifth	90	0	2	0	92	147	95	0	0	242
	Total	476	50	17	0	543	648	210	1	0	859
Tailings	First	53	2	0	0	55	260	10	2	0	272
	Fourth	47	4	6	0	57	181	167	5	0	353
	Germ	65	22	73	0	160	186	56	2	0	244
	Total	165	28	79	0	272	627	233	9	0	869
Low grade	First	49	6	15	0	70	168	83	4	0	255
	Second	12	0	0	0	12	207	90	6	0	303
	Third	80	3	18	0	101	271	26	3	0	300
	Total	141	9	33	0	183	646	199	13	0	858

Discussion

Due to the possibility of insects escaping from the salve tins within the milling machinery, it was necessary to seal the lids of the containers with masking tape. The high moisture content of the stock (Table I) coupled with the high temperature within the machines (TableII) allowed the mold spores present on and within the wheat kernels to develop rapidly within the sealed tins (Christensen, 1957). In every instance where a monthly sample showed no insect life, mold contamination of the food supply was heavy. Both _C. turcicus_ and _C. ferrugineus_ will eat mold which may be present on the surface of food in a culture tube (Liscombe, unpublished data), but when mold growth is heavy the oxygen may be depleted by the mold and the insects would die.

When temperature and relative humidity become marginal for _C. turcicus_, development and reproduction may be adversely affected. Bishop (1959) and Lefkovitch (1962b) said the optimum temperature for the development of this insect is 70 and 82°F., respectively, coupled with a high relative humidity. Previous experiments in this study have shown that 90°F. and a high relative humidity allowed the insect to develop rapidly. This makes it difficult to explain the difference in numbers of offspring of _C. turcicus_ produced on the different foods on the basis of temperature and relative humidity, as all mill stocks were close to 90°F. (Table II) and moisture content was high.

It is also difficult to explain the fact that a larger population of C. turcicus was observed on middlings than on tailings or low grades, as previous laboratory work showed middlings to be a poorer food for the increase of the species. A possible explanation may be that the slightly higher temperatures of some of the grades of the tailings and low grades fractions had an adverse effect on oviposition and larval development.

C. ferrugineus develops faster above 90°F. than below this temperature (Rilett, 1949). Almost identical numbers of this insect were produced in 30 days on middlings, tailings and low grades (Table XXXXI), a great many less on breaks. The reduced number on the break fraction may be due to the slightly lower temperature of this fraction in relation to the other three, and the heavy mold growth on the food. It appeared that C. turcicus was more able to compete with mold growth.

Lefkovitch and Milne (1963) suggested that if C. ferrugineus and C. turcicus were to gain access to cereals together, dry conditions, coarse food, low larval density and the availability of refuges for pupation would favor the development of large populations of C. ferrugineus; moist conditions, fine food, moderate to high larval density and the absence of refuges for pupation would favor large populations of C. turcicus. They did not elaborate on what they considered to be moist or dry conditions, nor low, moderate or high larval density. Although the species were reared separately in the present study, coarse food favored growth of C. turcicus rather than C. ferrugineus and fine food favored C. ferrugineus rather than C. turcicus. This reversal of results may be due to the fact that Lefkovitch and Milne (1963) were basing their reasoning on laboratory data while the present results are based on an experiment carried out in the mill.

The laboratory results obtained by Bishop (1959) showing that C. ferrugineus developed more rapidly than C. turcicus at low densities have been confirmed in this thesis. Lefkovitch and Milne (1963) stated that C. turcicus appeared to develop faster and that more of the progeny survived on fine food than was found with C. ferrugineus. The present study showed that under the crowded, and somewhat artificial conditions in flour mill machinery, C. turcicus developed faster than C. ferrugineus but more offspring were produced by the latter.

Crowding increased cannibalism in C. ferrugineus (Ashby, 1961); and in T. confusum (Boyce, 1946; Chapman, 1928; Chapman and Baird, 1934a; Chapman and Whang, 1934b). Crowding also reduced oviposition of O. surinamensis, A. obtectus (Say) and S. cerealella (Ol.)(Crombie, 1942); of S. granarius (L.)(MacLagen, 1932) and of T. confusum (Park, 1933). In the present study, approximately one third of the C. ferrugineus larvae and a few of the C. turcicus larvae died in the 30 day period. Although the cause of death is not known, cannibalism may have been partly responsible. Even though the mortality of *C. ferrugineus* larvae was higher than the mortality of *C. turcicus* larvae, there were roughly one and one half times as many live larvae of *C. ferrugineus* as of *C. turcicus* at the end of the 30 day period when 20 pairs of a dults were placed in each tin. These results take into account some of the factors (environment and mortality) which would affect *C. ferrugineus* living within milling machinery, and the results indicate that this insect may become a pest in flour mills in temperate regions of the world.

CHAPTER XII

SUMMARY

The aim of this investigation was to determine possible effects of milling fractions of bread wheat when used as food media on the biology of *Cryptolestes turcicus* Grouv. and *Cryptolestes ferrugineus* (Steph.). *C. turcicus* is an important pest of flour mills in temperate regions of the world and *C. ferrugineus* is an important pest of stored grain. The possibility of *C. ferrugineus* becoming a pest in flour mills in temperate regions was also investigated.

Most of the experimental work was done in the laboratory, but one experiment was done in a flour mill where the insects were reared within the milling machinery.

The 12 mill stocks used as food media in this investigation were collected from within the roll stands in a local flour mill. A sufficient quantity of each stock was secured at the one time to prevent possible differences in chemical composition of the stocks which might be evident in different mill runs. A portion of each stock sample was chemically analysed for protein, ash, fiber and fat content.

The insects used throughout the investigation were obtained from cultures of insects originating in rural Manitoba. These cultures were maintained in gallon jars using flour plus five per cent by weight of wheat germ as the food medium.

The thesis was divided into sections called chapters, each dealing with one aspect of the effect of mill stocks on the rate of development, survival, fecundity or rate of increase of the species. During the course of the investigation certain aspects of the life history of C. turcicus were noted. Eggs were laid loosely in the food material and hatched in three to 12 days depending on the temperature and relative humidity of the environment. The larva passed through four instars, the last instar being partly spent as an immobile prepupa. During the latter part of the third instar or early in the fourth instar, a pair of silk glands was formed on the ventral surface of the first thoracic segment. These silk glands developed rapidly and a tough silken cocoon was generally formed before the larva transformed to the prepupa. The newly formed adult remained in the cocoon for approximately two days while the integument hardened and darkened, the adult then chewing its way out of the cocoon to feed and search for a mate.

The effect of mill stocks on the rate of development and survival of C. turcicus was determined at a relative humidity of 90 per cent and at temperatures of 90, 80, 70 and 60°F., and of C. turcicus and C. ferrugineus at 90°F. and 70% R.H.

At 90% R.H. and 90, 70 and 60°F. there was no significant difference in the rate of development between individuals on the three grades of any of the four milling fractions. At 80°F.

and 90% R.H. development on third middlings was significantly slower than on first or fifth middlings, the latter two of which were equal. Development on germ tailings was significantly slower than on first or fourth tailings, the latter two of which were equal.

At 90% R.H. and 90, 80 and 60°F. there was no significant difference between per cent survival on the three grades of the four milling fractions, but at 70°F. there was a significant difference between fraction grades of breaks, middlings and low grades. Survival on fifth break was significantly lower than on first or third break, on third middlings it was significantly lower than on first or fifth middlings and on second low grade it was significantly higher than on first or third low grade. In each of the above fractions, there was no difference in survival on the latter two grades.

When the grades of each of the four fractions were averaged, there was no significant difference between rate of development on breaks, tailings and low grades at 90°F. and 90% R.H., while at 80°F. and 90% R.H., development on tailings was significantly faster than on breaks and low grades, but there was no difference between the latter two. At 70°F. and 90% R.H. development was significantly faster on breaks and low grades than on tailings. At 60°F. and 90% R.H. development was significantly slower in the breaks than on tailings and low grades. Development was significantly slower on middlings than on any other fraction at all four temperatures and 90% R.H. The number of days required for development was increased by roughly 50 per cent for each ten degree F. drop in temperature until 60°F. was reached where development time was double that required at 70°F.

Survival was not affected by milling fraction at 90 or 70°F. and 90% R.H. At 80°F. and 90% R.H. survival was fairly uniform on breaks, tailings and low grades but was significantly lower on middlings. At 60°F. and 90% R.H. there was no significant difference in survival on middlings or tailings, but survival on middlings was significantly lower than on breaks or low grades.

At 90°F. and 70% R.H. there were no significant differences in the rate of development between grades or fractions for C. turcicus. Survival was significantly lower on middlings and tailings than on breaks and low grades. At the same temperature and relative humidity the rate of development of C. ferrugineus was not altered by grades of the break or tailings fractions, but a significant difference was observed between all three grades of middlings, the rate of development being increased as grade was lowered. Third low grade significantly lengthened the rate of development over that obtained on the other two grades of the fraction.

The rate of development of C. ferrugineus was more rapid than that of C. turcicus on breaks, tailings and low grades but equal on middlings at 90°F. and 70% R.H. More C. *ferrugineus* than *C. turcicus* survived on middlings, tailings and low grades while survival on the break fraction was about equal for both species.

When *C. turcicus* was reared under crowded conditions at 90°F. and 70% R.H., significant differences in the number of F_1 adults formed were observed between all four fractions. The largest number was produced on tailings, the smallest number on middlings. There were no differences in the mean number of days required to produce F_1 adults between breaks, tailings and low grades, but significantly longer time was required on middlings. Significant differences in the number of F_1 adults formed were also observed between all three grades of breaks and tailings. On the break fraction, most adults were formed on the third grade followed by the first and then the fifth grades. On tailings, most F_1 adults were formed on germ tailings followed by the fourth and then the first grades. Significantly fewer adults were formed on the first low grade than on second or third low grade, the latter two being equal. No differences were observed between grades of middlings where few adults were formed.

Significant differences in the mean number of days required to produce F_1 adults were obtained between all three grades of the break fraction with the number of days increasing as the grade was lowered; between all three grades of middlings with the number of days increasing from that on fifth middlings to first middlings to third middlings. The number of days required to produce F_1 adults on first tailings was significantly longer than on fourth or germ tailings, and on first low grade it was significantly longer than on second or third low grade. The latter two grades of the tailings and low grade fractions were equal.

The number of offspring produced per female of each species in 30 days at 90°F. and 70% R.H. showed that for C. turcicus, significant differences were found between grades and fractions. On breaks, the number of offspring produced decreased as grade was lowered. On middlings, tailings and low grades the numbers increased as grade was lowered except on germ tailings which was poorer than the other two tailings grades but equal to first break. When grades of each fraction were averaged, the number of offspring produced per female of C. turcicus in 30 days was 8.8, 4.3, 42.0 and 29.1 for the break, middlings, tailings and low grade fractions, respectively. For C. ferrugineus, more offspring were produced on first break than on the other two grades which were equal; equal numbers were produced on fifth and third middlings, both of which produced significantly more than on first middlings; equal numbers were produced on fourth and first tailings with significantly fewer being produced on germ tailings, and equal numbers were produced on third and second low grades while significantly fewer were produced on first low grade. When grades of each fraction were averaged, the number of offspring produced per female of C. ferrugineus in 30 days was 18.0, 12.9, 23.1 and 20.1 for the break, middlings, tailings and low grade fractions, respectively. These results are higher than those for C. turcicus on the break and middlings fractions and lower on tailings and low grades.

There were no significant differences in the number of eggs laid by C. turcicus at 90°F. and 90% R.H. between the break, tailings and low grade fractions, but significantly fewer eggs were laid on middlings. On the basis of grades, significantly fewer eggs were laid on tailings as the grade was lowered. More eggs were laid on fifth break and fifth middlings than on first and third break or first and third middlings in that order. Significantly fewer eggs were laid on third low grade than on first or second low grade. There was no difference in the number of eggs laid between first and second break or first and second low grade.

C. turcicus laid significantly fewer eggs at 90°F. and 70% R.H. on the break and low grade fractions than on tailings. Fewer eggs were laid on middlings than on any other fraction. The number of eggs laid by C. turcicus on first break was significantly lower than that on either third or fifth breaks which were equal. Significantly fewer eggs were laid on fifth middlings than on first or third middlings which were also equal. No significant differences in the number of eggs laid were observed between grades of the tailings fraction, but significantly fewer eggs were laid on first and third low grades than on second low grade.

C. ferrugineus laid more eggs than *C. turcicus* on all fractions except tailings. The mean number of eggs for the four fractions was 65.0 eggs per female or 7.7 eggs per female more than for *C. turcicus* over a period of seven weeks. There were no significant differences in the number of eggs laid by *C. ferrugineus* on tailings and low grades, but fewer were laid on the break fraction. Egg production on middlings was significantly lower than on any other fraction.

C. turcicus laid most eggs per female per week during the second week of the seven week oviposition period on each of the four fractions, the rate then falling steadily for the remainder of the period. *C. ferrugineus* laid more eggs than *C. turcicus* except during the first two weeks, and continued to lay eggs at a fairly constant rate during the remainder of the seven week period. Tailings was preferred for egg laying by *C. turcicus* while the break fraction was preferred by *C. ferrugineus*.

Significantly fewer eggs were laid by *C. turcicus* at 90°F. and 70% R.H. on coarse food than on fine food, but there was no preference for particle size on the part of *C. ferrugineus*.

When reared in flour mill machinery for a period of eight months, *C. turcicus* produced roughly half as many offspring as did *C. ferrugineus*. *C. turcicus* increased in numbers most rapidly on the break fraction followed by middlings, low grades and tailings in that order. Middlings was the most suitable fraction for the increase of *C. ferrugineus* followed by tailings, low grades and breaks. Neither species showed any pattern from month to month in the number of offspring produced.

When reared under crowded conditions in flour mill machinery each species still produced roughly the same number of offspring per female as they did when not crowded. The results indicated however, that under crowded conditions *C. turcicus* developed more rapidly than did *C. ferrugineus*. This was a reversal of results obtained when larvae of each species were individually reared.

The results obtained in the various experiments indicated that milling fractions and their official grades would, under certain conditions of temperature and relative humidity, affect the rate of development, survival and fecundity of *C. turcicus* and *C. ferrugineus*. The information obtained is of value to the milling industry in the establishment of measures required for the control of *C. turcicus* and the frequency at which they must be applied. The results also indicated that *C. ferrugineus* may become a pest in flour mills in temperate regions.

Interpretation of results

The aims of this investigation were two-fold: to assess the possibility that *C. ferrugineus* might become a mill pest in temperate regions of the world, and to determine the effects of mill stocks when used as food on the biology of *C. turcicus* to plan the type and frequency of control measures required in the mill.

These aims have been investigated on the basis of the three criteria: rate of development, survival, and fecundity, under controlled laboratory conditions of 90°F. and 70% R.H. These conditions are comparable to those found in mill machinery during operations in temperate regions.

Table I of the appendix lists comparative values as calculated from the results obtained in the laboratory for the two species concerning rate of development, survival, and fecundity. *C. ferrugineus* developed more rapidly than did *C. turcicus* on all foods except middlings where the rate of development was equal for both species. *C. ferrugineus* had a higher survival than *C. turcicus* on all foods except the break fraction where survival of the two species was equal. *C. ferrugineus* laid more eggs than *C. turcicus* on all foods except tailihgs where *C. turcicus* laid 20 per cent more eggs than *C. ferrugineus*.

In eight months, *C. ferrugineus* produced roughly twice as many offspring as did *C. turcicus* when the species were reared in sealed containers in the milling machines. *C. ferrugineus* produced the greatest number of offspring in a 30 day period on the tailings fraction in both laboratory and mill tests, even though the mill tests were carried out in sealed containers and probably did not represent actual mill conditions. In a comparable period, *C. turcicus* produced the greatest number of offspring on the tailings fraction in laboratory experiments.

On the basis of rate of development, survival, and fecundity, *C. ferrugineus* was equal or superior to *C. turcicus* on most foods at a temperature and relative humidity roughly equivalent to what would be found under mill conditions. This indicates that *C. ferrugineus* may become a serious pest in flour mills in temperate regions of the world. *C. ferrugineus* is an important grain pest in Canada and can reproduce and develop rapidly in stored wheat and thus be transported to the elevator portion of the mill. Because it is a strong flier, there is a possibility that it might gain access from the elevator to the mill machinery by flight.

Rate of development, survival, and fecundity data for *C. turcicus* indicate that large populations of this pest are most likely to occur in those sections of the mill carrying the tailings and low grade fractions. Corrective measures for control must be applied once every four weeks if each generation of *C. turcicus* is to be controlled.

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APPENDIX A

SALIENT RESULTS OF COMPARATIVE EXPERIMENTS

Fraction	Rate of development[1]		Survival[2]		Fecundity[3]	
	C. turcicus	*C. ferrugineus*	*C. turcicus*	*C. ferrugineus*	*C. turcicus*	*C. ferrugineus*
Break	1.06	1.29	0.72	0.70	0.57	0.84
Middlings	1.01	1.00	0.43	0.82	0.25	0.35
Tailings	1.13	1.26	0.40	0.62	0.90	0.72
Low grade	1.10	1.26	0.72	0.80	0.58	0.75

[1] 25 divided by the number of days required for development (hatching of egg to adult emergence with the rate of development of *C. ferrugineus* on middlings adopted arbitrarily as a standard).

[2] survival divided by 100.

[3] mean number of eggs per female divided by 100.