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The Separation of Grain by Projection

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THE SEPARATION OF GRAIN BY PROJECTION[1]

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ABSTRACT

A device is described which effects a continuous separation of internally infested wheat from sound wheat, and which separates wheat into a number of fractions of different test weight. A stream of wheat, projected into still air by rapidly moving belts, is dispersed by the combined effects of air drag and gravitation into numerous fractions which are caught in a series of hoppers. Infested kernels fall short of sound grain and are thus separated. Test weight varies progressively and characteristically with distance from the point of projection.

Recently, extensive studies have shown that the principal source of microscopic insect fragments in milled products is internal infestation (6). The removal of external insects from grain constitutes no particular problem in commercial cleaning. The milling process has been modified to reduce insect fragments in milled products about as far as presently appears economically feasible (4), and separation of internally infested grain from sound grain would be extremely desirable. At the present time there is no device in use by grain processors which effects this separation (6).

The present report deals with the development and application of an apparatus which eliminates internally infested kernels from a stream of grain and which separates grain into fractions of increasing test weight on a continuous and rapid basis.

General Considerations

Grain cleaners in current use grade primarily by behavior in air currents and by length and width of the kernels. Insects develop within kernels of all sizes and shapes and do not affect these dimensions. An intact infested kernel may be differentiated from a sound one of the same size and shape by mass differences (10), by differences in transparency to X-rays (8), by staining of the egg plug (5, 7), and by the sounds generated by an internal insect (1).

The apparatus here described is designed to take advantage of the mass changes induced in a wheat kernel as the insect develops. A stream of kernels moving with uniform speed is projected into still

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air. Acted on by air drag and by gravitation, the grain is dispersed in such a way that infested kernels tend to fall short of sound ones of the same size and shape. The dispersed grain is collected into a series of hoppers.

Mathematical analysis of the problem is possible only when the drag is directly proportional to the velocity. At low velocities where Stokes Law applies, such analysis shows (9) that trajectories of different spheres projected from the same point with the same initial velocity are dispersed according to the parameter, mass/radius. Although most grains are not spherical, similar considerations apply. Under these conditions any separation which is effected depends not upon density (mass/volume) but upon the factor of mass/diameter. To effect a practical separation the drag forces must be greater than those prevailing under conditions where Stokes Law applies. Increased drag may be obtained by increasing the velocity of the kernel with respect to the air (2). At the velocities required for this separation, the drag force is no longer proportional to the velocity, the flow is turbulent, shape differences affect the motion, and a general mathematical analysis is not possible.

The separation principles outlined above, involving the interaction of grain with a fluid medium such as air or water, have been used for cleaning grain for centuries. Winnowing and aspiration are common examples involving the use of air as the fluid medium while the wet stoner is a familiar application involving the use of water. The present apparatus represents a carefully planned and controlled refinement of these methods.

Many of the details of the present apparatus were anticipated in a device patented almost a century ago by an inventor named J. L. Booth (3). Apparently, however, grain cleaning requirements at that time did not justify its commercial development.

Apparatus

The grain projection device, called a grain spectrometer by the authors, is illustrated diagramatically in Fig. 1. It consists of a hopper, *A,* with an adjustable slide-feed regulating device, two parallel belts, *B* and *C,* driven at the same speed, and a series of receiving hoppers numbered 1 to 16 into which the grain is received. The belt speed employed in these tests was approximately 1380 ft. per minute (700 cm. per second). The apparatus was adjusted to project the grain upward at an angle of approximately 25° from the horizontal. The space between the adjacent surfaces of the belts was made variable by

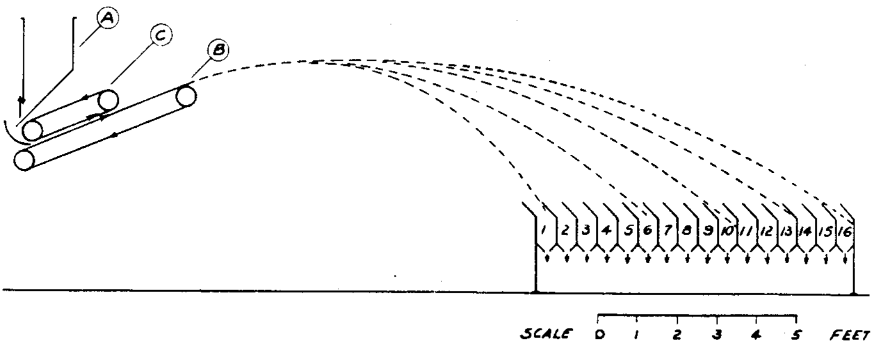

Fig. 1. The grain spectrometer.

providing adjustments for the pulley bearings of the top belt, *C*. As operated, this space between the two belts was approximately that of a single layer of wheat. Although the dimensions of the various components of the apparatus are not considered critical, it has been drawn to scale as shown.

Performance

Fractionation of Commercial Wheat on the Basis of Test Weight. The first evaluation of the grain spectrometer involved fractionation of an ordinary sample of sound wheat. For this experiment, 5 bu. of

TABLE I

TEST WEIGHT OF WHEAT FRACTIONS OBTAINED BY SPECTROMETRIC SEPARATION

Hopper No.	Fraction	Test Weight
	%	*lb/bu*
Original sample	. . .	61.4
1	0.33	55.0
2	0.55	55.5
3	0.84	56.6
4	1.37	57.6
5	2.58	58.4
6	4.04	59.5
7	6.98	60.4
8	12.28	61.1
9	14.84	61.5
10	16.60	61.9
11	14.49	62.6
12	12.80	63.0
13	8.50	63.1
14	3.26	63.3
15	0.47	64.0
16	0.14	. . .[a]

[a] Quantity collected too small for test weight determination.

commercial No. 2 hard red winter wheat of 61.4-lb. test weight were used. This grain had received a preliminary cleaning by passage through a milling separator. The grain was processed in the grain spectrometer and the fractions collected in the hoppers were weighed and analyzed for test weight with a standard Boerner weight-per-bushel apparatus.

The results are shown in Table I. A regular change in test weight from 55.0 to 64.0 lb. per bushel was observed. The modal hopper was No. 10, which received 16.6% of the sample, and this fraction had a test weight of 61.9. The grain varied in appearance from thin, shriveled, and broken kernels in hoppers 1, 2, and 3 to grain of increasing plumpness in the hoppers of higher number.

To evaluate the reproducibility of the spectrometer's performance the grain which had been originally collected in hoppers numbered 6 through 13 was separately reprocessed. Specimen results are shown

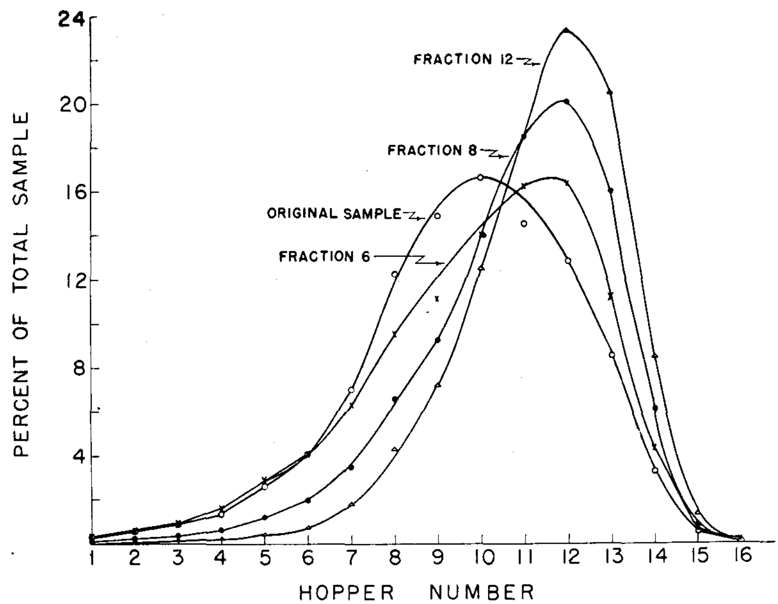

Fig. 2. Distribution of fractions from original sample and of reprocessed fractions 6, 8, and 12.

in Fig. 2. This graph shows the data for the original sample as well as for three reprocessed fractions. It is evident from these curves that the present apparatus does not separate grain with absolute precision into homogeneous and reproducible fractions. Higher hopper numbers become increasingly homogeneous in terms of the modal hopper

TABLE II

DISTRIBUTION OF TEST WEIGHT IN FRACTIONS

Sample	Test Weight	Percent of Sample in Given Range of Test Weight		
		61 and Lower	61.1-62.5	62.6 and Higher
	lb.	%	%	%
Original sample	61.4	16.7	42.2	40.7
6	59.5	51.0	44.0	5.0
7	60.4	31.2	50.7	17.8
8	61.1	23.8	53.4	23.0
9	61.5	9.9	36.9	53.0
10	61.9	4.3	40.9	53.5
11	62.6	2.3	31.0	66.6
12	63.0	. . .[a]	<14.9	85.1
13	63.1	. . .[a]	<14.3	85.7

[a] Quantity collected too small for test weight determination.

(No. 12) owing to the removal of low test weight fractions. Further analysis of the data resulting from the reprocessing is shown in Table II. Here the test weight of the original wheat and the test weights determined for each of the fractions 6–13 are shown. Each of these fractions was reprocessed through the spectrometer and data for test weight were broken down into three categories to show the test weight composition in the fractions. The relative amount of high test weight wheat is shown to increase markedly with bin number.

TABLE III

SPECTROMETRIC SEPARATION OF INTERNALLY INFESTED WHEAT

Hopper No.	Fraction of Original Sample (by Weight)	Fraction Infested (by Kernel)
	%	%
Original sample	100.0	8.5
1	0.1	27.0
2	0.1	40.8
3	0.2	45.3
4	0.3	29.5
5	0.6	33.4
6	0.4	30.9
7	2.2	30.9
8	4.8	12.5
9	8.2	11.7
10	14.0	7.9
11	20.2	6.0
12	23.9	1.5
13	17.7	1.9
14	6.3	0.2
15	0.8	1.1
16	0.2	2.7

Fractionation of Wheat on the Basis of Infestation. Sixteen fractions were obtained from a sample of 16 kg. of wheat known to contain 8.5% of infested kernels. The infestation of the original wheat and the fractions was determined by radiographic inspection of 20-g. samples. The total number of kernels and the number of infested kernels shown on each radiograph were determined. The percentage distribution of fractions and percent of kernels infested appear in Table III. It is evident that a marked concentration of infested kernels occurred in the hoppers closest to the point of projection (1–7), whereas the grain falling in hoppers 12–15 was relatively free of infestation. Thus hopper 12, which received 24% of the sample, contained only 1.5% of infested kernels. Similarly, adding together all the wheat collected in hoppers 12–16, we find that 49% of the sample was reduced in infestation to approximately 1.5%, representing a sixfold purification.

Several of the radiographs from which the above data were obtained are shown (Fig. 3a-c). These supply visual evidence of the marked reduction of internal infestation achieved by one pass through the grain spectrometer.

The contents of hoppers 1–6 inclusive, which together constituted less than 2% of the total sample by weight, were about 35% infested (Table III). These fractions were discarded. The intermediate fractions were composited and reprocessed with the result that the wheat found in hoppers 12–16 was significantly cleaner than the composited as well as the original sample.

Discussion

The ability of the grain spectrometer to separate commercial wheat into a number of test weight fractions on a continuous basis is obviously of considerable significance to the grain warehousing and milling industries. It seems probable that such apparatus could be readily integrated into the mechanical operations of mills and elevators, not only for the purpose of processing grain to provide fractions of specified test weight characteristics, but also to reclaim sound grain from commercial samples of low value.

The simplicity of the apparatus suggests its application on the farm to upgrade grain prior to marketing by improving test weight and by eliminating infested kernels. Other applications which suggest themselves but which have not yet been evaluated include separation of mixtures of grain of different species such as wheat and rye, separation of light oats from well-filled oats, separation of rodent pel-

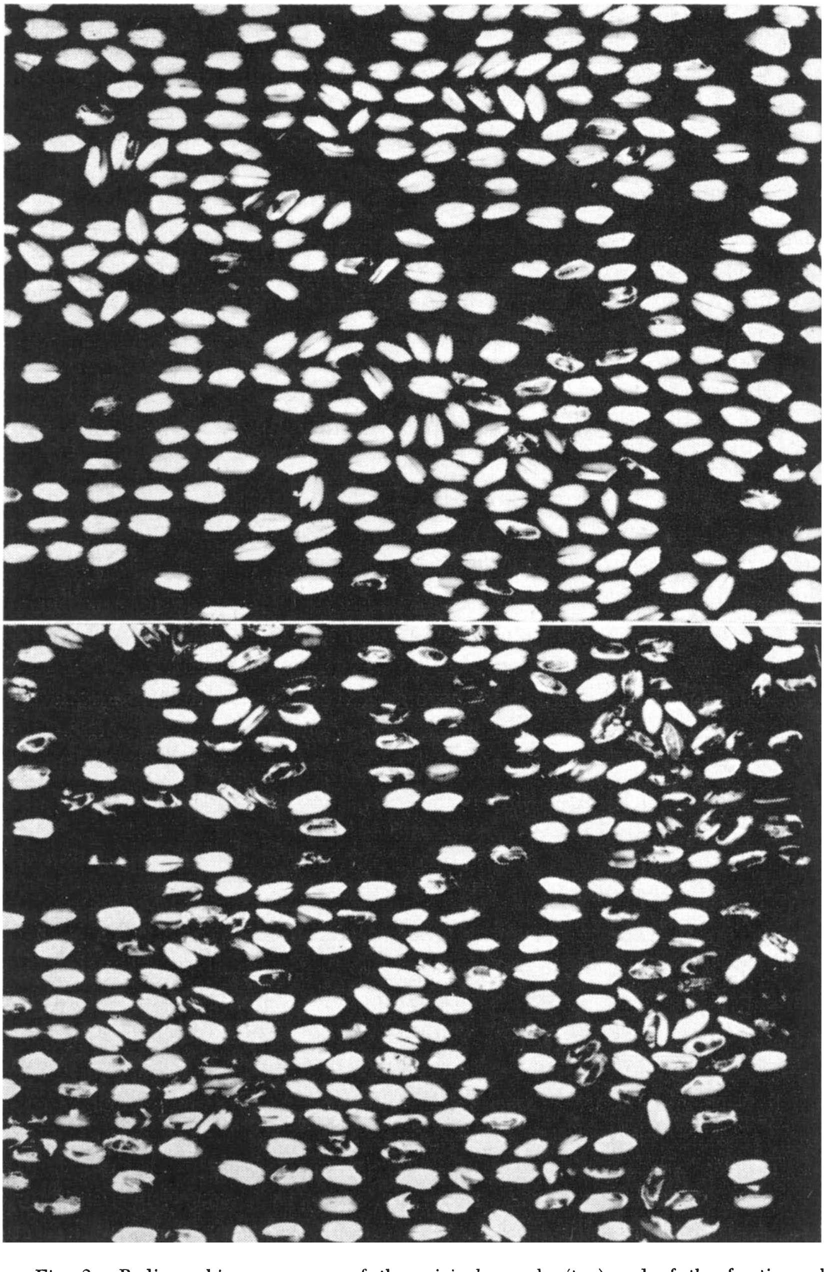

Fig. 3a. Radiographic appearance of the original sample (top) and of the fraction collected in bin 3 (bottom), showing the concentration of infestation in the bins closest to the point of projection.

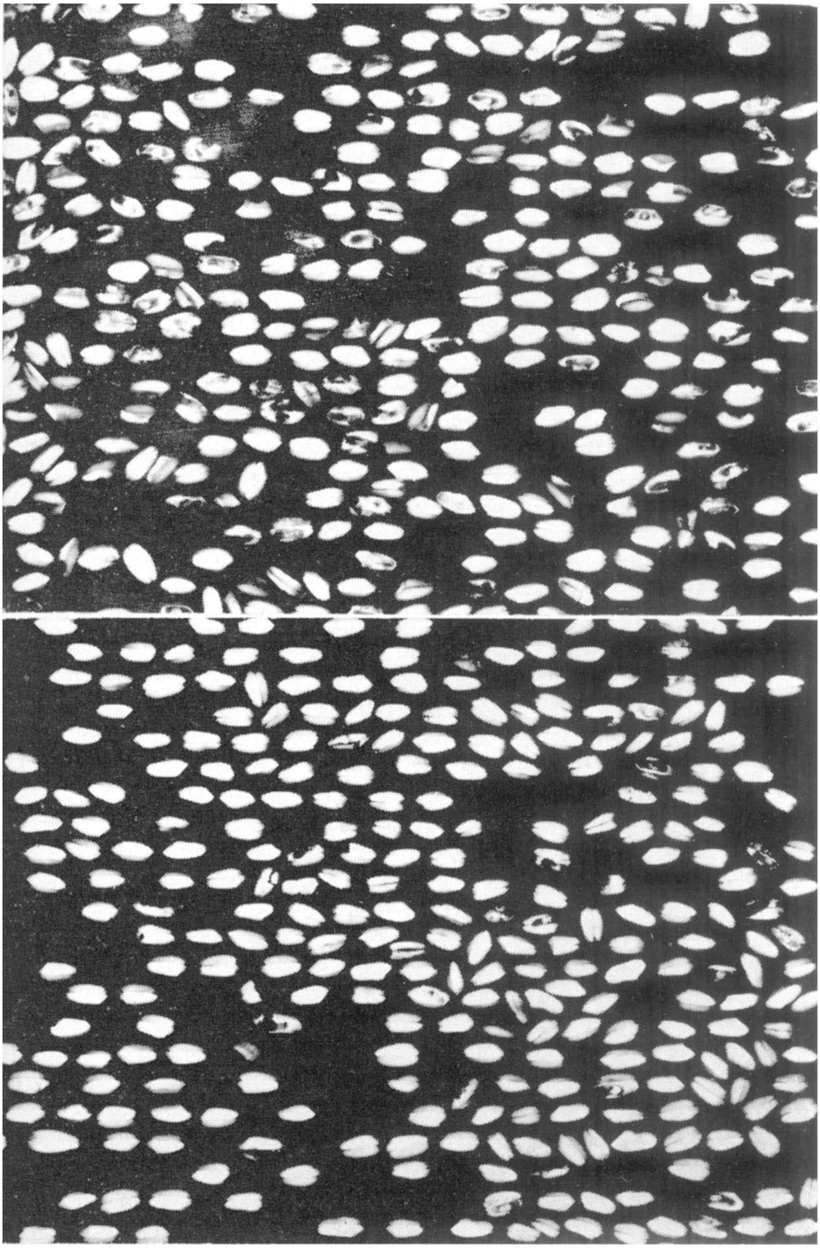

Fig. 3b. Radiographic appearance of intermediate fractions Nos. 6 (top) and 10 (bottom), showing progressive decrease in infestation with distance from the point of projection.

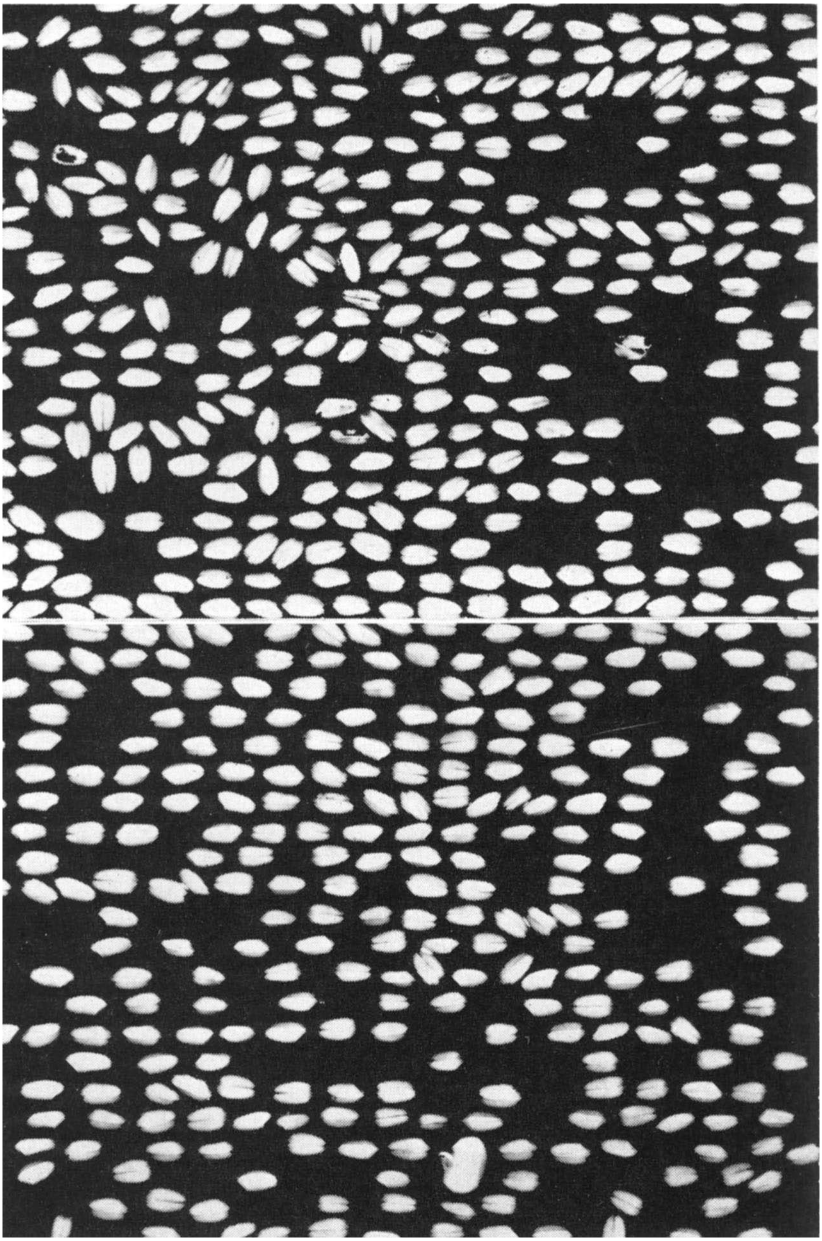

Fig. 3c. Radiographic appearance of fractions Nos. 12 (top) and 14 (bottom). Some corn kernels were segregated in the higher numbered bins. Note the relative freedom from infestation of the wheat falling in bin 14.

lets from corn and other grain, and separation of commercial seeds of all species into heavy, light, and intermediate fractions.

Differences in physical and chemical properties of the test weight fractions of a given wheat sample have been found, and the extent of these differences in terms of protein content, ash content, and technological properties of the grain will be shown in a subsequent paper.

The performance of the grain spectrometer in removing internally infested kernels suggests that a considerable amount of grain which would ordinarily be rejected for milling purposes because of excessive levels of internal infestation can be reclaimed. Thus it appears that a single pass of a lot of infested grain through such a machine would reclaim a significant proportion of the sample as sound grain. Refinements in apparatus and operating technics are now being developed which are expected to improve the resolution of the apparatus.

Literature Cited

1. Adams, R. E., Wolfe, J. E., Milner, M., and Shellenberger, J. A. Aural detection of grain infested internally with insects. Science **118:** 163–164 (1953).
2. Binder, R. C. Fluid mechanics, 2nd ed., p. 172 ff. Prentice-Hall, Inc.: New York (1949).
3. Booth, J. L. Grain separation. U. S. Letters Patent No. 23,153 (1859).
4. Farrell, E. P., and Milner, M. Insect fragment problem in the milling industry. Kansas Agr. Expt. Sta. Circ. 291. (Nov. 1952).
5. Frankenfeld, J. C. Staining methods for detecting weevil infestation in grain. U.S. Dept. Agr. ET-No. 256 (1948).
6. Harris, K. L., Nicholson, J. F., Randolph, Lila K., and Trawick, J. L. An investigation of insect and rodent contamination of wheat and wheat flour. J. Assoc. Offic. Agr. Chemists **35:** 115–158 (1952).
7. Milner, M., Barney, D. L., and Shellenberger, J. A. Use of selective fluorescent stains to detect insect egg plugs on grain kernels. Science **112:** 791–792 (1950).
8. Milner, M., Lee, M. R., and Katz, R. Application of X-ray technique to the detection of internal insect infestation of grain. J. Econ. Entomol. **43:** 933–935 (1950).
9. Synge, J. L., and Griffith, B. A. Principles of mechanics, 2nd ed., pp. 154–159. McGraw-Hill: New York (1949).
10. White, G. D. Weight loss in stored wheat caused by insect feeding. J. Econ. Entomol. **46:** 609–610 (1953).