INVASION AND PENETRATION OF CONSUMER PACKAGES IN SHORT-TERM STORAGE BY STORED-PRODUCT INSECTS

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Sections 402(a) of the Federal Food, Drug, and Cosmetic Act states that "A food shall be deemed to be adulterated--...(3) if it consists in whole or part of any filthy, putrid, or decomposed substance, or if it is otherwise unfit for food; or (4) if it has been prepared, packed, or held under insanitary conditions whereby it may have become contaminated with filth ...." In order to enforce this section of the Act, the Food and Drug Administration frequently becomes involved in court litigations to ascertain the avenue of contamination by insects of stored-food products. The question then arises as to responsibility for the contamination. Three possible avenues of contamination exist: infestation occurred during processing; construction of the package so as to offer avenues of invasion by adult and larval forms; or penetration by boring of adult and/or larval forms occurred after final packaging.

Evidence left by this last type of entry is most readily discernible by visual inspection of the package in most cases. Direction of boring can be determined by microscopic examination of the hole. Physical appearance of entrance and exit holes varies with the type of packaging. Characteristic types of damage caused by insects penetrating various packaging materials have been discussed in a previous publication [1]. In general it has been found that insect boring is characterized by a wider hole on the entrance side, tapering to a smaller exit hole.

Certain stored-product insects have been demonstrated to be penetrators of food packaging by boring, while other invaders require unsound packages to enter [2]. The cadelle, *Tenebroides mauritanicus* (L.), was among those insects listed as highly successful penetrators of packaging by Gerhardt and Lindgren [3]. The cigarette beetle, *Lasioderma serricorne* (F.), is also a well known penetrator. Stored-product moths such as the Indian meal moth, *Plodia interpunctella* (Hubner), are known penetrators in the larval stage. Species such as the flour beetles, *Tribolium* spp., and the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.), are known to be poor penetrators, based on studied of long-term storage conditions.

Evidence of insects in packages which have no apparent penetration holes indicates either the presence of insects at the time of packaging or invasion into unsound packaging. Gaps in seals or incomplete gluing of flaps indicate poor construction of packages. Research into package construction has shown that modern packaging techniques can prevent invasion by insects [4]. Transparent

films such as cellophane and polyethylene are heat-sealable and thus the problem of incomplete closure is eliminated. For those packages constructed of paper, fiberboard, and laminates, it has been found that hot-melt glue-sealed closures are more effective against insect invasion than either heat seals or cold glue-sealed closures [5]. Construction of multilayer paper bags involves gluing of seams and flaps; closure of fiberboard containers also is dependent on glue. If the seals are discontinuous, insects can enter the package. Species such as *O. surinamensis*, have small flat adult stages which are quite active, allowing them to seek out and enter through small openings.

The purpose of this study was to determine the ability of several common storage pests to infest consumer packages of different types of penetration and/or invasion over a short-term storage period of four weeks. This study also was made to develop a means to identify the characteristics of package construction which allows invasion and the physical appearance of penetration sites in packaging material.

MATERIALS AND METHODS: Insects used in this study were taken from cultures reared on standard culture media in an insectary. Adult and larval forms of coleopterous insects and larval forms of lepidopterous insects were used in this test. The species tested were; *Tenebroides mauritanicus* (L.) - cadelle, *Lasioderma serricorne* (F.) - cigarette beetle, *Tribolium confusum* J. duV. - confused flour beetle, *T. castaneum* (Herbst) - rust red flour beetle, *Oryzaephilus surinamensis* (L.) - sawtoothed grain beetle, *O. mercator* (Fauvel) - merchant grain beetle, *Ephestia elutella* (Hubner) - tobacco moth, and *Plodia interpunctella* (Hubner) - Indian meal moth.

Insects were placed in wide-mouth, one gallon jars with the test packages. The packaging consisted of cellophane bags with glued seals, polyethylene bags with hot-melt closures, multilayer foil and paper bags with glued closures, Kraft paper multilayer bags with glued flaps and stitched tape closures, and fiberboard boxes with glued flap closures. All packages were purchased from retail market grocery shelves. Packages were visually examined before testing to assure package integrity. A jar containing intact packages was kept free of insects as a control to assure that the presence of insects would indicate contamination before purchase.

Fifty moth larvae and 100 beetles (50 adults and 50 larvae) were placed in individual glass jars with the test packages. The contents of the jars were examined after four weeks and the number of live and dead insects were recorded. Packages constructed of Kraft paper and fiberboard were examined microscopically before opening to determine package integrity at glued flaps and seam closures. Any penetration holes on the packages were noted and examined. The packages were then opened and the contents were examined for the presence of insects. Packages which contained penetration holes were examined under a wide-field microscope at 30X and the condition of the packaging material was recorded.

RESULTS AND DISCUSSION: Table I illustrates the ability of the various species tested to infest consumer packages by penetration and invasion. The cadelle, *T. mauritanicus*, was the only species tested which was able to penetrate all packages tested. Penetration into laminated foil and paper packaging was made by cadelle larvae only. Both adult and larval forms penetrated the remaining types of packages. The cigarette beetle, *L. serricorne*, was the only other species tested which penetrated the test materials. Adult forms were more active than larval stages and bored at various points on the package. Boring by the larval stage was concentrated at the bottom seams of the packages unlike cadelle larvae, which bored indiscriminately. Both species concentrated boring activity in locations where leverage could be achieved with legs or body.

TABLE I. Penetration and Invasion of Packages by Stored Product Insects in Short Term Storage[a]

Package Type	Penetration	Invasion
Laminated foil and paper	a	
Cellophane bag	a, b	
Polyethylene bag	a, b	
Multilayer paper bag	a, b	e, f
Fiberboard box	a, b	c, d, e, f

[a]a = Cadelle, b = cigarette beetle, c = confused flour beetle, d = red rust flour beetle, e = sawtoothed grain beetle, and f = merchant grain beetle. The tobacco and Indian mothes did not penetrate packing materials in this study. Larval stages only were tested.

Invasion of packages was made most often by the sawtoothed and merchant grain beetles. Adult survival of these two species was the highest of all tested (Table II).

TABLE II. Average Survival of Stored Product Insects During Four Week Test Period.

Species	% Survival Adult	Larvae[a]
Tenebroides mauritanicus	72	60
Lasioderma serricorne	74	82
Tribolium confusum	90	54
Tribolium castaneum	80	38
Oryzaephilus surinamensis	94	66
Oryzaephilus mercator	98	54
Ephestia elutella[b]	--	66
Plodia interpunctella[b]	--	68

[a]Larvae which pupated were counted as viable.
[b]Larval specimens only were used in the test.

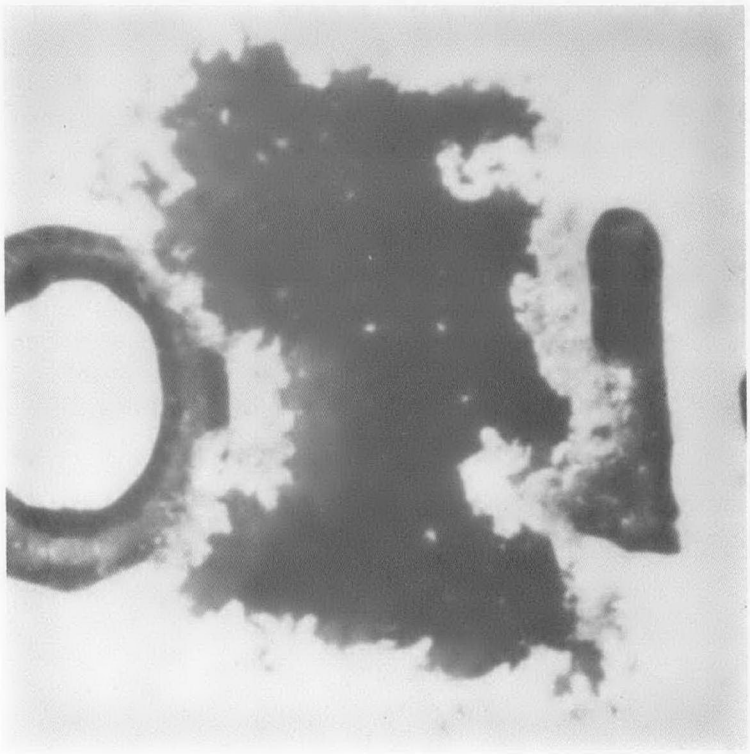

FIGURE 1. Penetration hole of the cadelle, *Tenebroides mauritanicus*, into cellophane wrap.

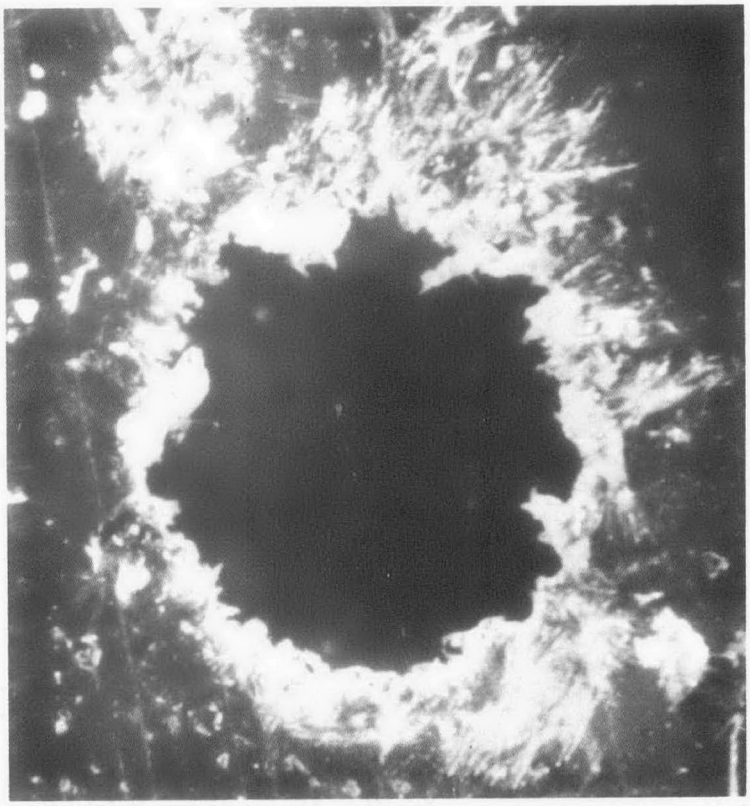

FIGURE 2. Penetration hole of the cigarette beetle, *Lasioderma serricorne*, into polyethylene wrap.

FIGURE 3. Penetration hole of the cadelle, *Tenebroides mauritanicus*, into paper.

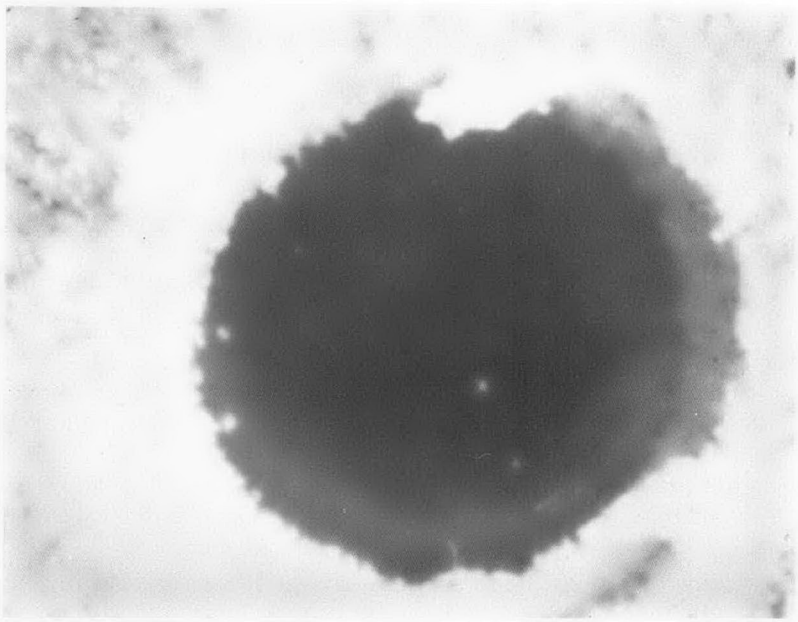

FIGURE 4. Penetration hole of the cigarette beetle, *Lasioderma serricorne*, into fiberboard.

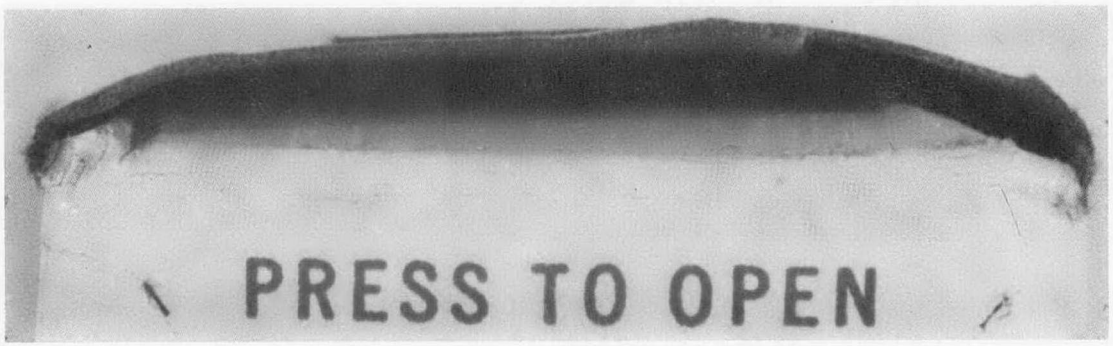

FIGURE 5. End flap of fiberboard box showing lack of seal.

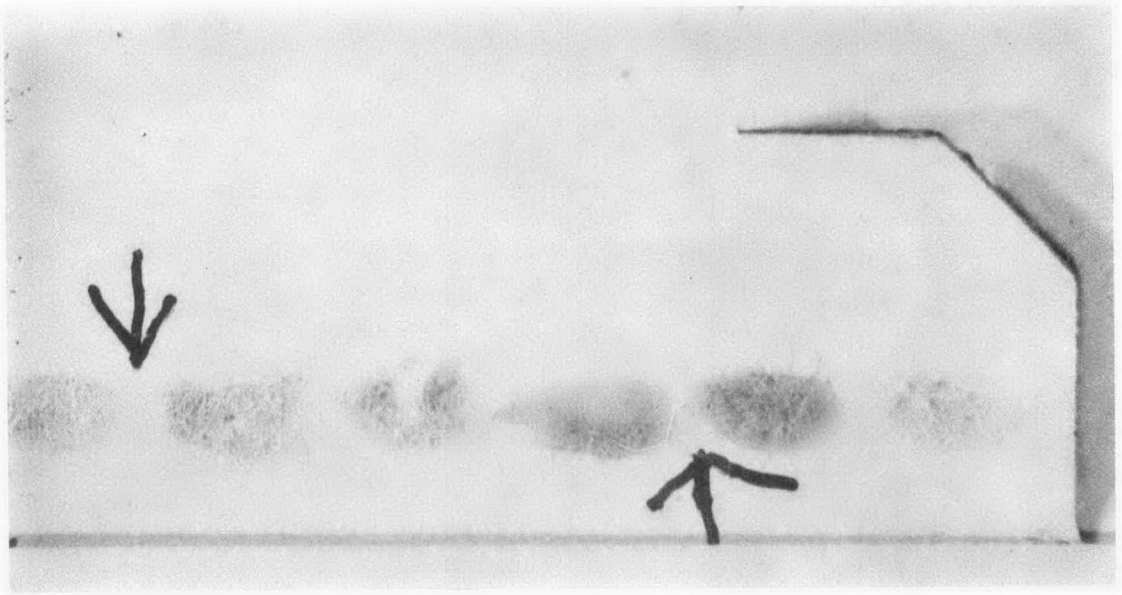

FIGURE 6. Top panel of fiberboard box showing glue seal with gaps allowing invasion of insects.

The overall survival of adult insects was higher than for larval forms after the test period. The average survival for adult insects after four weeks was 84.7% and average larval survival was 61.0%. The lowest survival was among *Tribolium castaneum* larvae (Table II). Cannibalism was observed in this species during the test. *Tribolium* spp. invaded fiberboard boxes which had larger gaps in the end flaps than multilayer paper bags.

The penetration holes made by cadelle and cigarette beetles were unique between each other and among the packaging materials tested. The entrance hole of the cadelle was irregular in shape (Fig. 1); whereas the hole made by the cigarette beetle was smaller and symmetrical (Fig. 2). The type of hole also differed by the type of damage done to the packaging material. Penetration of cellophane (Fig. 1) was characterized by a cratered depression of the material with no fraying of material. Polyethylene packaging

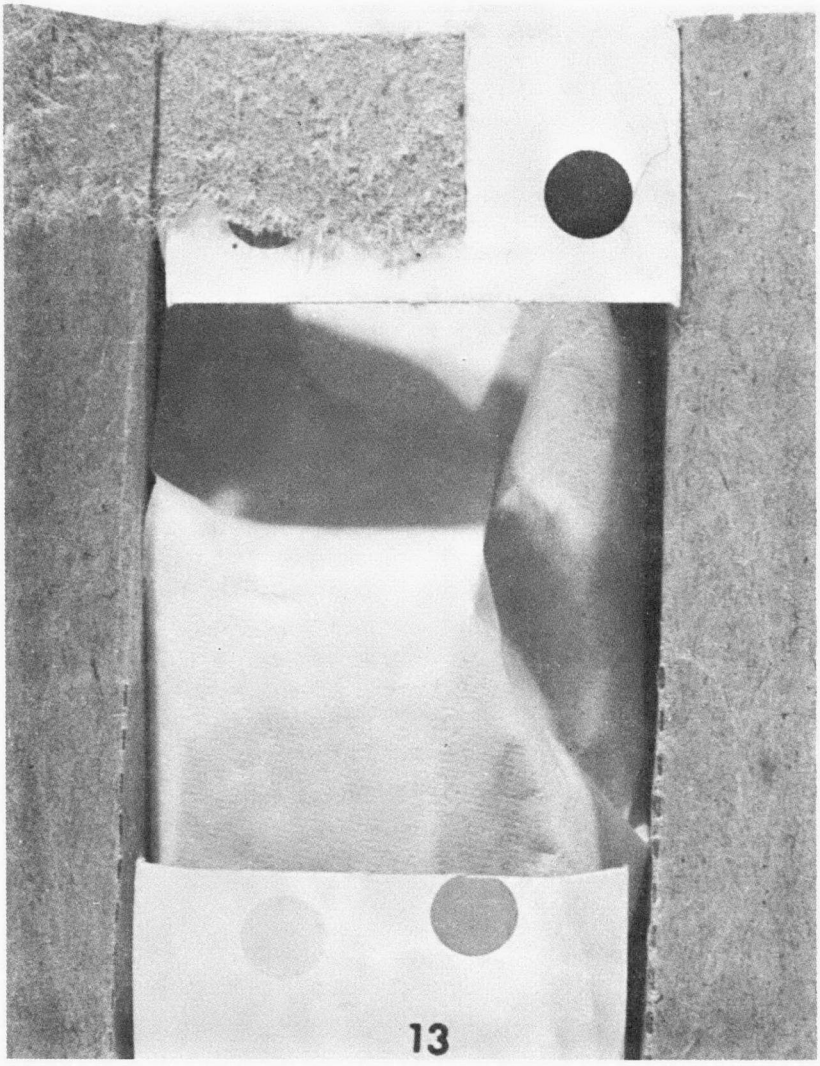

FIGURE 7. Opened box showing only one of four points sealed.

(Fig. 2) showed evidence of mandibular scratches and up-turned edges toward the entrance side, indicating the material was softer than cellophane. Penetration into paper bags (Fig. 3) showed fraying of fibers and up-turned edges toward the boring side with the diameter of the hole decreasing with depth. Similar evidence was noted on fiberboard boxes (Fig. 4) with less fiber fraying. Multilayered foil and paper wraps appeared least affected by either invasion or penetration by insects. The size of the gap left in sealing packages determined which species invaded packages. Multilayered paper bags and fiberboard boxes were most susceptible to invasion due to their construction. *Tribolium* spp. as well as sawtoothed and merchant grain beetles entered through unsealed flaps of fiberboard boxes.

The flat shape of sawtoothed and merchant grain beetle adults and their constant searching activity apparently aided entry into the product. Infestation of paper bags and fiberboard boxes occurred by invasion through incompletely sealed end closures

(Fig. 5) and gaps in glue on the flaps (Fig. 6). Invasion through the latter sites could be prevented by slowing down the glue dispensing, making a complete glue seal on end flaps to eliminate gaps, and sealing all points on end closures (Fig. 7). The size of the insect may be a determining factor in invasion by larger species such as the cadelle and larval moths; however, the cigarette beetle, which is of smaller stature, was not observed to invade the packages tested.

Packages were not penetrated in this study by *Plodia interpunctella* or *Ephestia elutella* larvae, both of which are known penetrators of packaged food. The length of time required for penetration and the type of packaging which can be penetrated by moth larvae will be investigated in future studies. Additional work is also needed with respect to other stored-product beetles and their method of entry into packaged food. Authentic penetration holes made by insects in this study can be used for reference in cases where insects are found in stored foods.

In summary, these observations indicate that penetration and invasion of consumer packages are possible in short time periods. The seal of the packages, particularly paper bags and fiberboard boxes, is important in the ability of small, active insects to invade a package. The direction of boring of these species can be easily discerned by microscopic examination. This technique is a useful tool in analyzing the cause of live insect infestation in consumer packages of food by FDA.

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