Filth in Foods: Implications for Health

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ABSTRACT

Filth is defined in this context as any objectionable matter contributed by animal contamination of a food product, such as insect, rodent, or bird matter, or any other objectionable matter contributed by insanitary conditions. The Federal Food, Drug, and Cosmetic Act insists upon high levels of sanitary practice in the food industry as a means of both preventing filth from getting into food and preventing any disease that may be associated with such filth. There are three categories of pest-food relationships: (a) accidental (e.g., bird feathers, bat feces), (b) opportunistic (e.g., foraging by ants, rats), and (c) obligatory (i.e., pest survival largely dependent on food gathered and cached by man). Food pests or fragments thereof may act as direct agents of disease by causing dermatosis, allergy, myiasis, and toxicogenic effects (the latter as yet unproved in man). Food pests may also serve as mechanical or biological vectors of human pathogens. In contrast to the sort of mainline vectoring done by malaria mosquitoes, food pests, where they are involved at all, usually transmit pathogens only along pathways that are peripheral and supplementary to epidemiologically more important routes of transmission.

THE FOOD LAW

The meaning of the Federal Food, Drug, and Cosmetic Act, as it applies to food sanitation, has been defined in publications of the Food and Drug Administration (48, 102). We may safely conclude from these official statements that it is not necessary to demonstrate a cause-and-effect relationship between extraneous materials in foods and disease to substantiate an enforcement action under the Act. Most enforcement actions are based on evidence of extraneous material in the food product and/or on evidence that storage or processing was done under insanitary conditions.

Yet prevention of disease is clearly one of the objectives of the Act and inherent in the Act is the idea that this objective is best achieved by conducting every aspect of food handling under the most sanitary conditions attainable. In short, the employment of "good manufacturing practices" (GMPs) is a technique of preventive medicine.

FOOD, FILTH AND HEALTH

Insects as food

Those members of the human family still innocent enough to be classed as hunter-gatherers do not, as many of us would, categorically reject insects, bats and rodents as human food (for examples see 16 and 28), although they may shun certain animals or parts thereof because of their intrinsic or reputed poisonous qualities. Even today, as in past centuries, insects are routinely enjoyed as condiments or delicacies in the diet of large segments of human society, especially in the "emerging" countries (15). Because of this history of entomophagy with impunity, it has been suggested (20) that no legal restraints should be placed on occurrence of insect fragments and similar contaminants in food, save only that the label should accurately report their presence. It would be left to the discretion of the consumer to buy or not to buy.

Food sanitation and infant mortality

As food supplies dwindle with increasing populations, it may well be necessary to reconsider sanitary standards in the food industry. Certainly large segments of the world's population, living today under generally insanitary conditions, attach little or no significance to the presence of insects in food or to the remarkable aggregations of flies and cockroaches so often associated with foods; the technological trappings that complicate their otherwise simple lives make them no less oblivious of the Germ Theory than the Arunta of Australia or the Masarwa of Africa, whose insect-eating habits have been so graphically described by Bodenheimer (15).

Such societies are often characterized by a high infant mortality rate, largely a reflection of the effects of virtually universal infant diarrhea, exacerbated by an insanitary environment (42) and inadequate nutrition (105). Adults in these societies are armed with an impressive array of antibodies, but even these defenses can be lowered by aging, malnutrition, and a variety of mental and physical stresses. Visitors to such societies, likely coming from more sanitary surroundings, quickly learn to admire the immunity of their hosts but often fail

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1FDA Project Number 04182, "Health Significance of Insects in Food." Microanalytical Branch, Division of Microbiology, Bureau of Foods. This discussion is restricted to filth originating from or disseminated by arthropods, birds, rodents, bats, and other mammals. The term "filth" is included within the meaning of "extraneous materials," which means any foreign matter in product associated with objectionable conditions or practices in production, storage, or distribution; included are filth (any objectionable matter contributed by animal contamination such as rodent, insect, or bird matter, or any other objectionable matter contributed by insanitary conditions), decomposed material (decayed tissues due to parasitic or nonparasitic causes), and miscellaneous matter such as sand and soil, glass, rust, or other foreign substances (bacteria excluded) (49).
to appreciate that the price paid for it was a high infant death rate.

In contrast, the lower infant mortality rates extant in much of Western civilization have been purchased in part by a heavy investment in preventive medicine, including an abiding allegiance to GMPs in the food industry. Pathogens are still here, even in our highly sanitized and artificially immunized society; that they are sometimes deterred in reaching new hosts is largely the result of good sanitation in the food industry. At least one dependable indication of whether or not the food industry is adhering to GMPs is provided by quantitative analysis of food to detect extraneous matter (49).

**Competition for food**

Compared to the amount of information available on foodborne illnesses in general, it would appear that relatively little is known about filth-associated illnesses. There are a few good examples of filth-associated disease and some of these will be mentioned subsequently. In most instances, however, the evidence of cause-and-effect is circumstantial or hypothetical and must be viewed with appropriate circumspection.

Human foods are attractive to a wide variety of animals. Competition for nutritive substances is keen and continuous. Pests of the food industry may be counted upon to take full advantage of every opportunity to convert human food to their own use (9). To prevent this, nothing less than constant vigilance is required of the food industry. But even under the best of circumstances it is difficult to consistently provide the consumer with food products completely free from contamination by food pests.

**Food pests**

The steps required to bring a crop from farm to family may be few or many depending on variables of product, season, and geography. Generally, the fewer the steps, the fewer (or simpler) the pest problems (and vice versa), but even those products requiring the fewest steps—fresh fruits and vegetables—may already be well supplied with pests of garden, farm, and orchard. All of the edible portions of field and orchard crops are affected by an assortment of pests—aphids, bugs, leafhoppers, thrips, caterpillars, maggots, grubs, mites, mice, birds, etc.

After the crop is harvested and started through some sort of processing, the food material encounters two general classes of pests: (a) those associated mainly with the food itself (e.g., rice weevil, cheese mite, almond moth, larder beetle, Indianmeal moth, fruit fly), and (b) those associated with and often to some degree dependent upon buildings, that is, an artificial environment created by man around the food (e.g., German cockroach, silverfish, house fly, Australian spider beetle, house mouse, Norway rat, pigeon, little brown bat).

**Pest-food relationships**

In the case of roosting birds and bats, and in those instances where dogs and cats are used for rodent control, the contact between pest and food is largely *accidental*, as when hairs, feathers and excrement chance to fall on unprotected food or food-handling surfaces (47). Other pests (e.g., German cockroach, Pharaoh ant, Norway rat) are largely *opportunistic* with regard to food. Their populations fluctuate with the availability of food, but they also require harborage and water. A third category of pest-food relationships could be described as essentially *obligatory*. The food material provides the pest (e.g., warehouse beetle, rice weevil, Mediterranean flour moth) with all the necessities of life. The rationale behind good housekeeping in home and factory immediately becomes apparent. A high standard of sanitation deprives pests of the food reserves they require to tide them over intervals of scarcity between shipments of more desirable foods.

It would be unwise to overlook here the chance that another type of unfortunate event may also occur, namely, the inadvertent insertion of pests into packages of food. Or, still another, the placement of clean foods into a container in which a pest has taken refuge. In other words, quality control must be linked with good housekeeping to form a consolidated line of defense against the pervasive opportunism of food pests.

**Pest prevention**

Prevention of pest infestation is generally most taxing with pests in the “*obligatory*” category; the long-standing ecological intimacy of pest and food is disrupted only with difficulty. Preventing infestation by pests of the “*opportunistic*” category is somewhat less difficult but certainly not easy. These pests are the product of a prolonged association with man; they have persisted tenaciously in that association in spite of the best efforts of man to part company with them. Preventive techniques, usually consisting of the denial of access to roosting sites, are the least difficult to employ and are often used successfully against the “*accidental*” category of pests.

**Pest invasion and quality control**

Evidence of contamination of foods by pests in all three categories may be expected to appear at any stage in the journey from field to kitchen. However, after foods have been sealed in packaging materials other than metal or glass and are resting in a dry condition in a warehouse, grocery or pantry, only those pests that possess the morphological tools to breach the defenses of the package and the physiological tools to cope with the internal milieu of the package may be expected to prosper. Other pests, less well endowed, may follow in the footsteps of the primary invaders.

**AGENTS AND VECTORS**

Food pests may adversely affect man either by direct action (as agents) or by indirect action (as vectors).

**Transmission routes**

Two types of vectors are apparent: (a) mechanical vectors, effecting transmission of a pathogen by its...
simple removal, either on the body surfaces or in the gut, from one point to another (this act, however, must have some epidemiological significance for a new host to qualify as transmission); and (b) biological vectors, in which the pathogen enters the gut (but may migrate from there to other parts of the body), multiplies or develops (or at least arrogates significant life support), and passes on (but not necessarily directly or immediately) to a susceptible host. This transfer of the pathogen to a new host may be accomplished by ingestion of the entire vector or some infected portion thereof, or by ingestion of, injection of, or contact with some material, usually food or water, contaminated with pathogen-bearing excreta or egesta. Transfer by contact implies that the pathogen must actively penetrate some external defense of the host or else take advantage of some existing breach such as a break in the skin.

In all instances where food pests may be actually or theoretically involved as mechanical or biological vectors, the role they play is relatively minor. The pathogens have other, more efficacious routes. For example, salmonellosis would doubtless persist as an important disease even if there were no flies, cockroaches, ants, or rats. But the presence of these potential vectors increases the probability that salmonellas will successfully meet new hosts. Also, the presence of these pests usually indicates an insanitary environment (110), one in which the nonvector mediated chains of transmission are more likely to be successfully forged.

**FOOD PESTS AS DIRECT AGENTS**

**Dermatosis**

Straw itch mites (*Pyemotes ventricosus*) prey on the larvae of several kinds of insects, among which are some food pests—bean weevil, pea weevil, and Angoumois grain moth (2). These hosts normally provide the mites with all the water and nutrients they require. But the mite populations are, for reasons unknown, given to rapid expansions. The mites may tolerate a scarcity of food, but they are keenly susceptible to dehydration. When that occurs they urgently seek new sources of water. Any person coming within the sphere of their peregrinations is very likely to be attacked, the resulting dermatosis being caused by insertion of the mite mouthparts into the skin (32).

**Injectant allergens**

The best known allergic responses to arthropods are those caused by bites and stings (34, 91, 101). Allergens entering the human body by injection are referred to as injectant allergens. Straw itch mite dermatosis is an example of this phenomenon. Other routes of access to the human body are available to offending allergens: dermal (but not injected), pulmonary, and oral. The study of food contaminants as ingestant allergens is complicated, of course, by the fact that when certain foods, even though wholesome and pure, are consumed they may produce allergic symptoms (92).

**Contactant allergens**

The Indianmeal moth (*Plodia interpunctella*) has caused contact dermatitis in Bulgarian walnut shellers (52). Several species of food-associated mites also serve as contactant allergens. No penetration by mouthparts is involved here; merely direct contact between the skin surface and the mites (especially the body fluids of crushed mites) is all that is required to produce a transient dermatitis (18). These mites are associated with a long list of food products, some of which are cheese (*Acarus siro*, *Tyrophagus putrescentiae*), copra (*T. putrescentiae*), bran (*Suidasia nesbittii*), and dried fruits, jams, sugar (*Carpophagus lactis, Glycyphagus domesticus*) (109).

**Inhalant allergens**

The fact that food pests can function as inhalant allergens is best demonstrated by instances in which allergic symptoms (rhinitis, asthma) developed in persons working in an insectary where food pests were reared (*Sitophilus granarius* (33); *Trogoderma* spp. (87); *Leucophaea maderae* (14)). Bernton and Brown (14) suggest that particulate matter from live or dead and disintegrated cockroaches may cause asthma. Marchand (75) substantiates this idea with his report of successful desensitization of asthmatics with roach extracts. He also suggests that inhaled particles of bat feces may cause asthma (75).

There appears now to be no doubt that a major factor in the cause of “house dust allergy” are mites of the genus *Dermatophagoides* (76). These mites are found most commonly in houses, especially in bedrooms. But, as they feed mainly on desquamated human epidermal scales, they may be found any place that is frequented by man. Dermatophagoides mites have as yet no special connection with the food industry, but at least two other mites, *Acarus siro* and *Glycyphagus domesticus*, both definitely associated with food, may also be inhalant allergens (120).

**Ingestant allergens**

The inadvertent ingestion of insects and mites, or fragments thereof, present as contaminants in foods, is commonplace (89) and generally no untoward effects result. That the human body often responds at least subclinically to these insults has been conclusively demonstrated by Bernton and Brown (12). They recorded positive skin reactions to extracts of food pests in 30% of 230 allergic persons and in 25% of 194 “non-allergic” persons. Shown here are the percentages of positive reactions among 333 allergic and non-allergic subjects for each of the pests tested: *Plodia interpunctella*, 24%; larval *Tribolium castaneum*, 23%; adult *T. castaneum*, 14%; *Sitophilus oryzae*, 9.6%; *Drosophila melanogaster*, 9%; *Tribolium confusum*, 6%; and *Rhizopertha dominica*, 5.7%.

Cockroaches are particularly suspect as ingestant allergens because of their frequent and intimate contacts with human food (14, 21, 75). Bernton and Brown (13)
have also shown a relationship between degree of sensitization, severity of infestation, and duration of exposure to cockroaches. Since many foods are heated during some stage of processing or preparation, it is important to note that cockroach allergen resists heating at 100 C for 1 h (14).

Live arthropods in food

The larvae of several kinds of flies live as parasites in animals (57). The passing of this larval phase in a suitable host is an essential part of the life cycle. This kind of invasion of animal tissues is called obligatory myiasis. A similar term, facultative myiasis, denotes the ability of certain fly larvae, which normally live in dead flesh, to also invade living organs or tissues (usually at the site of a wound or some other lesion on the skin).

The fact that people sometimes accidentally consume living insects and mites has already been mentioned (59). If fly larvae are so eaten, the phenomenon is called accidental enteric myiasis, distinguishing it from the parasitic myiases mentioned above. If mites are eaten, the phenomenon is called accidental enteric acarasis (109); if beetles, accidental enteric canthariasis; if moths, simply scoleciasis. These accidental arthropodias bear little resemblance to the orderly host-parasite relationships seen in obligatory or facultative myiasis. Instead of deriving shelter and nutriments from the host, the accidentally-ingested arthropod is more likely to be met with a fatal barrage of mechanical and chemical insults from the unwilling host. Yet a few of these invaders manage to survive for various periods and some even succeed in emerging alive from the host.

Dead arthropods in food

Ingestion of dead arthropods or their dejecta that chance to be present as contaminants in food is a phenomenon that does not fall within the definitions myiasis, canthariasis, etc., but the presence of such filth in food would, if the food were imported or placed in interstate commerce, constitute a violation of section 402(a)(3) of the Federal Food, Drug, and Cosmetic Act.

Probably all arthropods, whether ingested alive or dead, function in some degree as ingestant allergens. The antigenic capabilities of six common food pest species have been demonstrated in rabbits (53).

Scoleciasis

If no other reason than because the Indianmeal moth so frequently infests candy bars (in the United States, at least), people probably eat more larvac (either alive or dead) of this species than any of the other kinds of arthropods that are likely to be accidentally ingested. This hypothesis is supported by the fact that the highest rate (24%) of positive reactions in the skin sensitivity tests of Bernton and Brown (12) was to Plodia interpunctella. Nevertheless, scoleciasis is rarely reported (100).

Myiasis

In contrast to the meager record of scoleciasis, there are many reports of accidental enteric canthariasis and myiasis (89). Several kinds of flies deposit their eggs on fresh fruits, especially on imperfections. Drosophilid fruit flies, often associated with tomato products, are probably ingested more frequently than other flies, but no deleterious effects of this have been noted. However, the results of skin sensitivity tests with Drosophila melanogaster (12) and the speculations of Sturtevant (106) on the role of drosophilids as vectors suggest that this group of flies may have some small significance for human health.

Intestinal upsets of considerable severity have been associated with Muscina stabulans (23) and with Hermetia illucens (77); both species are known to deposit their eggs on overripe fruit. Larvae of the cheese skipper (Pliophila casei) are likely to be ingested; at least two cases of bloody diarrhea have been linked to this fly (90, 111). These accidental cases are supported by an experiment in which 83% of 60 volunteers promptly developed gastrointestinal disturbances of brief duration after swallowing fly larvae (Musca domestica) in capsules (60).

Canthariasis

In another experiment (79) human volunteers ate oatmeal spiked with beetles (Tribolium confusum) and their dejecta. No untoward effects were observed. The same result followed ingestion of Sitophilus granarius (94). But again, on the basis of the experiments by Bernton and Brown (12), it must be emphasized that such a seemingly innocuous insult, especially when experienced by a young child, may provoke a chain of sensitization reactions that may result, probably at a later stage in life, in overt allergic expression.

Dermestid larvae (Trogoderma sp.) were recovered from the feces and from the food (a dry, high-protein baby cereal) of a four-month-old child suffering from ulcerative colitis (87). In a similar case, larvae of Trogoderma ornatum were found in baby cereal which had been fed to an infant who subsequently suffered acute gastroenteritis (87). Particularly suspect in these two cases are the setae with which dermestid larvae are so generously clothed. It is hypothesized that dermestid setae, which are notably tenacious and invasive of soft tissue, may be able to produce numerous foci of physical and antigenic trauma along the alimentary canal. I offer a further suggestion, entirely hypothetical, regarding an additional causative factor in these two episodes: the larval metabolites in hemolymph, excreta and dejecta may have been toxicogenic, producing at least some of the described symptoms.

Toxicogenic effects

It has long been known that certain by-products of insect metabolism impart a disagreeable taste, odor, and appearance to flour and also impair its baking qualities (103). In the case of certain tenebrionid pests of grain and flour, these disagreeable characteristics are caused by quinone secretions (65). Experimental results with mice offer some evidence that these quinone compounds
may be tumorigenic and toxicogenic (66, 107), but these results require further confirmation. Compounds of similar biological potency, namely, tryptophan derivatives excreted by cockroaches *(Periplaneta americana, Leucophaea maderae)*, are carcinogenic or mutagenic when applied to mice (83, 84). Signs suggestive of direct toxic action were seen at necropsy in rats that had been fed flour infested with mites (82). That compounds of such remarkable biological activity are produced by arthropods so intimately and routinely associated with food raises serious question as to their true significance in human health.

**FOOD PESTS AS VECTORS**

There are three general groups of potential vectors associated with food: (a) birds and bats (important because of their indiscriminate deposition of droppings or because pathogen-laden fecal particulates may become airborne, foodborne, or waterborne); (b) cockroaches, flies, ants, mice, and rats (important because they habitually and indiscriminately visit sources of pathogens—drains, discarded dressings, floors, sewers (17), feces, and sardy other ejecta—and human food or food-handling surfaces, and because they persistently or temporarily harbor pathogens on or within, and shed pathogens from, their bodies; and (c) the "pantry pests" (various mites, moths, and beetles that so commonly infest dry foods), not widely considered to be vectors because their life histories are often played out within a rather circumscribed territory surrounding some source of food.

*Pathogen dispersal*

While it is generally true that the meanderings of pantry pests do not often take them to good sources of pathogens, it is equally true that the more mobile pests (ants, mice, etc.) are capable of routinely bringing pathogens to the home ground of the pantry pests. From that point of contact pantry pests may mechanically disseminate pathogens throughout the food and thus serve effectively as still another link in the chain of fecal-oral transmission.

Some work has been done on the question of pantry pests as mechanical vectors, but the matter remains largely unsettled (22, 44, 50, 58, 81, 114). However, the fact that stored-grain insects and mites are competent disseminators of *Aspergillus* spores (19) lends credence to the notion that they may also disperse other suitable pathogens. Although conclusions regarding the role of food pests in the epidemiology of foodborne microbial infections must remain tentative for the present, researchers at the University of Minnesota have made important contributions to our understanding of one pest, the lesser mealworm (*Alphitobius diaperinus*), as a disseminator of bacteria, fungi, and viruses (25-27, 45, 49). Similar studies of other pest species will be required before their vectorial significance can be properly understood.

**Enteric bacterial diseases**

The abundant literature on enteric bacterial diseases includes only relatively few instances in which vectors have played significant supportive roles in the chain of transmission, e.g., transmission of salmonellosis by mice (56), rats (104), cockroaches (41, 73), and flies (55); shigellosis by flies (64, 72); and cholera by flies (52). The role of cockroaches in the spread of salmonellosis has been reviewed by Bartlett (4). Greenberg (42) has comprehensively reviewed the role of filth flies as vectors.

That vectors have not been implicated more frequently in the spread of foodborne enteric pathogens may be in part due to surprisingly low rates of natural infection of the vectors, as least with rats and mice—1.2%, based on isolations from fecal pellets (116), and cockroaches—1.24% (95).

**Hospital infections**

Another factor may be that the potential role of vectors is simply discounted out of hand or not even considered by epidemiologists investigating outbreaks of gastroenteritis or other diseases. For example, in the very extensive literature on infections acquired in hospitals, no potential contributory factor is given less attention than vectors. Yet it is possible to find hospitals in which pathogen-laden arthropods routinely encroach upon food, upon surfaces with which food comes in contact, and upon other surfaces or articles presumed to be clean or sterile (5, 6-8, 40, 43, 69, 98).

The incident in which *Bordetella bronchiseptica* (cause of porcine bronchopneumonia) was transmitted by ants within a veterinary isolation unit is an especially instructive model for hospital epidemiologists (6).

**Leptospirosis**

Food pests enter the cycle of transmission of leptospirosis in only a very peripheral way. Leptospirosis is a common latent infection of domestic rats and mice (59, 113). These animals continuously shed leptospires in their urine. Desiccation, acidity, and salinity are all inimical to survival of the leptospires. Leptospires deposited in water, on a moist medium, on a damp surface, or in an atmosphere of very high relative humidity have some chance of surviving long enough to be infective. The usual routes of infection are oral, dermal (only through breaks in the skin), and through mucous membranes.

In a restaurant situation, leptospires deposited (with urine) on moist, ready-to-eat food of moderate temperature (80), or on moist food-preparation surfaces, utensils, and cloths, or in water in which utensils are perfunctorily rinsed, stand some small chance of meeting new hosts. In slaughter-house, meat-packing, or poultry-processing situations, leptospires deposited directly on carcasses or portions thereof, or in water that may contaminate meat or come into contact with receptive surfaces of the human body, also may infect new hosts. It seems unlikely that leptospires in urine shed by rats and mice onto packaged dry products, e.g., wheat
flour, would survive long enough to be infective.

**Histoplasmosis**

*Histoplasma capsulatum* is the causative agent of histoplasmosis, a saprophytic soil fungus (30). Pigeon, starling, and bat droppings that accumulate under roosts seem to serve the fungi as well as soil. Any physical disturbance of such substrates launches innumerable spores into the air. The spores may be breathed in or may be eaten with food on which they chance to fall. Although pigeons and starlings may feed on spilled grain or similar foods around some food industry operations, there is no intrinsic connection with food in the epidemiology of this disease. However, when food industry facilities are remodeled or added to, or when ground is cleared for new construction, any histoplasma spores that chance to be disturbed become airborne and settle indiscriminately on nearby surfaces.

**Aspergillosis, aflatoxicosis**

Molds of the genus *Aspergillus* are saprophytic on a wide variety of substrates. Some members of the genus are able to invade living tissues, including those of the human body. Thus, they are pathogenic as infective agents, as inhalant or contactant allergens, and also because they produce toxicogenic compounds (1). Aflatoxin, mainly from *Aspergillus flavus*, is a potent toxin and a suspected carcinogen in man (119). Sterigmatocystin, produced by *A. versicolor*, is carcinogenic for laboratory rats (63). Food pests, especially insects and mites, mechanically disseminate mold spores in stored grains (39). Since *A. fumigatus* and *A. niger* occur as natural infections in cockroaches (97), it may be presumed that cockroaches also disseminate mold spores.

**Ornithosis**

Transmission of the bedsonia pathogens of ornithosis is only slightly more direct than that of histoplasmosis. The pathogens of ornithosis are present within infected birds (pigeons, house sparrows, and many other species) and are shed in their droppings (24, 78). Droppings may fall upon food or food-handling surfaces, thus becoming directly incorporated into a situation in which transmission may occur. Or droppings drying and disintegrating elsewhere eventually release pathogen-laden particles that may contaminate food. Construction procedures mentioned earlier would in this instance also trigger aerial dispersal of the pathogens.

**Amebiasis**

Both flies (96) and cockroaches (97) carry natural infections of *Entamoeba histolytica*, the causative agent of amebiasis, but though the circumstantial evidence is suggestive, there has been no objective demonstration that these vectors are epidemiologically significant (42). **Toxoplasmosis**

Recent experimental work by Wallace (115) with *Toxoplasma gondii* in flies and cockroaches makes it possible to construct a hypothetical diagram of the epidemiology of toxoplasmosis (Fig. 1). There are two ways in which food pests may theoretically enter the cycle of transmission: (a) by dissemination of the parasites among wild and domestic animal reservoirs; and (b) by direct deposition of oocysts on foods consumed by man. Wild and domestic felines, especially house cats, probably play a central role in the propagation of *T. gondii*, but human infections appear to result mainly from transplacental passage or from ingestion of raw or inadequately cooked meat containing infective tissue cysts (25, 112). The possibility of contracting the infection by direct contact with cat feces should not be discounted (57).

**Chagas disease**

One of the many avenues of transmission in the labyrinthine epidemiology of American trypanosomiasis involves contamination of food by feces of triatomine vectors. The pathogens (*Trypanosoma cruzi*) remain infective in the feces up to ten days after being egested from the bugs (85). In many domestic situations in those regions where Chagas disease is highly endemic, there is ample opportunity for food to become contaminated with feces either by direct inoculation from bugs resting in thatched roofs or by means of airborne particulates.

**Diphasic milk fever**

There are several well-substantiated examples of diseases in which viruses, vectors, and foods are involved. In the first example, diphasic milk fever, the pathogenic viruses are conveyed to human hosts in raw goat milk (38). Ticks mediate the transmission of viruses between the goats and certain small mammals, and may also convey (by biting) the viruses to man. The epidemiology of
Q fever, a rickettsial disease, is similar to that of milk fever in at least two ways: the pathogens are shed in milk, and ticks may also transmit the pathogens (31). In these milkborne infections the vectors are not food pests nor do they have any direct association with human food. In the next two examples, however, the vectors are food pests and transmission may be effected by direct contamination of food and water by the vectors.

**Bolivian hemorrhagic fever**

The viruses of Bolivian hemorrhagic fever are shed continuously in the saliva and urine of the vector, *Colomys calossus*, a wild grass mouse (54). These mice, which are apparently unaffected by the viruses, regularly enter homes in search of food. When people ingest unheated food or water contaminated during these depredations, infection may result. The virus of lymphocytic choriomeningitis, a disease of house mice and other rodents, may be conveyed to man in a similar way (10, 71).

**Fowl leucosis**

These examples from exotic pathology were introduced here to show that the idea that pathogenic viruses may be conveyed to man via food or food pests is not merely hypothetical.

In this connection a transmission cycle from veterinary pathology is worth noting, even though some details remain unclear. Lesser mealworms, *Alphitobius diaperinus*, become infected with avian leucosis viruses while feeding on chicken litter or on moribund or dead chicks. Experimental evidence (29) supports the notion that many chicks that chance to eat infected beetles will develop the symptoms of avian leucosis. Although the beetles may serve as vectors of the virus, other transmission routes (transovarial, airborne droplets, direct fecal-oral) are probably more important.

**Enteric viral pathogens**

Some attention, long overdue, is now being given to the occurrence and behavior of viruses in foods (20, 61, 62, 67, 68, 93). These enteric or foodborne viruses (e.g., enteroviruses, adenoviruses, reoviruses, coxsackie A and B, infectious hepatitis, epidemic viral diarrhea, poliomyelitis, etc.) generally rely, like their bacterial counterparts, on a fecal-oral route of transmission (20, 93). Except for flies and cockroaches (42, 70, 86, 97, 108, 121), the food pests have been generally ignored as potential vectors of foodborne viruses.

**Arthropodborne viruses**

Among those viruses requiring a vector, the arboviruses are best known. Neither the arboviruses nor their vectors are of much concern to the food industry, but persons involved in the industry should be aware that many field crops are infected with plant viruses (phytoviruses) and mycoplasmas that are transmitted from plant to plant by insect and mite vectors (37, 74, 88). Certain foods, e.g., coleslaw, reach the consumer bearing live virus particles. These viruses, generally considered to be completely innocuous to man (99), are derived either from plant tissues or from the tissues of arthropods feeding on the plants, or both.

Many precisely identified viruses and mycoplasmas (118) have demonstrated their ability to thrive in both plant and arthropod systems. Many other viruses and mycoplasmas thrive in both arthropod and vertebrate systems (but, in contrast to the plant mycoplasmas, there is no indication yet that vertebrate mycoplasmas are vectored by arthropods). At the present time only speculative answers can be given to questions about evolutionary ties between these two great groups of viruses transmitted by arthropods (117) and to questions about what further evolutionary adaptations, particularly pathogenic ones, may be expected from the arthropodborne plant and animal viruses and mycoplasmas.

**VEHICLES OF IMMUNIZATION**

The concept of arthropods as agents and as vectors in the epidemiology of human disease fits comfortably within the framework of traditional medical entomology. But, as I have tried to imply, this concept, when rigorously applied to the question of health significance of food industry pests, tends to become hazy for lack of precise information. There is, however, an additional concept that is even less understood. Besides being agents and vectors, arthropods, as Barnett (3) has pointed out, may also serve in a third epidemiologic role, as vehicles of immunization. That is, by transmitting too few pathogens to produce overt infection (42) or by somehow attenuating the pathogens before passing them along, the arthropod provokes immunity rather than disease in the host. The peripheral position that arthropods usually hold in the natural cycles of foodborne disease transmission may make it all the more likely that they would function as vehicles of immunization rather than as vectors.

**CONCLUSION**

To conclude on these notes of uncertainty is appropriate because much of our thinking on this general topic—the relationship of food pests to human health—is shrouded with uncertainty. The uncertainty is largely due to two factors: the scarcity of cases (scarce either because they are in fact rare or just rarely recognized and reported), and the paucity of experimental data on the basic capabilities of food pests as agents and vectors of human disease. To dispel this uncertainty will require the methodical accumulation of a long series of case histories and experimental trials in which the cause-and-effect relationships are clearly discernible.

**REFERENCES**

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Two States have Adopted Water Quality Index

Two states, New York and Michigan, have designated the NSF Water Quality Index (NSF/WQI) for official use in making annual reports to Congress on the quality of their waters. These reports which are submitted via the EPA under Public Law 92-500 must also delineate progress in improving the quality of the state’s waters.

Nearly 100 scientists working under the auspices of NSF (National Sanitation Foundation, Ann Arbor, Michigan) have aided in the development of the index according to Robert M. Brown, president.

Water quality reports required by the federal law will answer such questions as: How good is the water in designated lakes and streams? Is it fit to drink? Will it support aquatic life? How does the water quality compare at various sampling points on the same lake or stream?

Selection of Parameters

State and federal water quality management experts were canvassed by mail for selection of index parameters (characteristics affecting water quality), to give their judgments on the effect of each parameter on water quality, and the relative significance of each parameter to other parameters.

The responses established nine major parameters including dissolved oxygen (oxygen in water), fecal coliform bacteria density (an organism in sewage), temperature, turbidity (suspended sediments) and various undesirable chemicals.

Dr. Nina I. McClelland says, “A water quality index number can be established for any water source with testing equipment that is standard for virtually all water departments in the U.S. by measurement of the nine factors.”

Among the parameters are those which, by themselves or in combination, aid the water quality expert in determining whether water is safe for human consumption or even contact with the body. Some help to determine whether fish and other aquatic life are able to survive in a lake or stream, or what kind of aquatic life survives and in what abundance.

For example, fish, like humans, require a sufficient amount of oxygen to live—some species more and some less. If pollutants rob the water of oxygen they die.

The level of alkalinity in water, or its opposite, acidity, can influence the quantity and quality of aquatic life. Water temperatures that are too high can steal life-giving dissolved oxygen.

Excesses of some chemicals from manufacturing, mining, and domestic sources result in pollution. Pollution is then catalogued into seven basic categories—organic, infectious bacterial, toxic, nutrient, mineral, thermal (high temperature), sediment and oil.

Participating Agencies

Working with the Ann Arbor NSF staff in development of the index were the Michigan Department of Natural Resources, U-M School of Public Health scientists, Notre Dame University, the Maryland Department of Water Resources, the Cleveland Clean Water Task Force, the U.S. Army Environmental Hygiene Agency, the Pennsylvania Department of Water Resources, the Ohio River Valley Sanitation Commission and the Larimer County Health Department in Colorado.

As the first state to apply the NSF mathematical index to its waters, New York has been able to show a dramatic improvement in water quality.

On April 15, New York made its water quality inventory report to Congress and in it, through use of the NSF/WQI, demonstrated water quality improvement in eight major rivers.