THE USE OF INFRARED AND MICROWAVE RADIATION FOR CONTROL OF STORED-PRODUCT INSECTS[1]

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ABSTRACT: Thermal energy obtained from either infrared or microwave radiation or from heat by convection can be used to control insects infesting stored products. The time required to obtain temperatures that are lethal to insects depends not only on the insect species but also on the moisture content and heat-retention characteristics of the grain or other commodities.

An infrared heater with a surface temperature of 926° C was tested; approximately 75% of its output was in the middle section of the infrared region; and peak emissions occurred at 2.5μ. The eggs and young larvae of lesser grain borers, *Rhyzopertha dominica* (F.), and Angoumois grain moths, *Sitotroga cerealella* (Olivier), infesting wheat were more resistant to infrared radiation than were the eggs and young larvae of rice weevils, *Sitophilus oryzae* (L.).

Microwave tests were conducted in an oven with a frequency of 2,450 MHz. The mature larvae and pupae of Angoumois grain moths, rice weevils, or lesser grain borers were more resistant to microwave energy than either the young larvae or eggs.

Convected heat was tested using elevated temperatures obtained with a chamber maintained at a constant temperature and RH. Air temperatures of 39° C with 60% RH gave 99% or more control of rice weevils, but a temperature of 43° C and 50% RH were required for control of lesser grain borers. Wheat quality appeared unaffected by storage temperatures of 49° C for either 1 or 2 months. However, the flour from this wheat did change color especially when the wheat samples were stored for 2 months.

INTRODUCTION: The term "radiation" as used in this paper will refer only to that portion of the electromagnetic spectrum that includes infrared and microwave frequencies. These wavelengths are longer than those of visible light but shorter than waves of radiofrequency below the UHF region. Also for convenience, the infrared spectrum is divided arbitrarily into three sections according to wavelength. Thus "near infrared" extends from 0.7 to 1.5μ, "intermediate" (or middle) extends from 1.5 to 5.6μ, and "far infrared" extends from 5.6μ to 1 millimeter.

Heat can be transmitted most efficiently by infrared

[1]Mention of a pesticide or a commercial or proprietary product in this paper does not constitute a recommendation or an endorsement of this product by the U. S. Department of Agriculture.

occurs below 200° C, and peak energy in the near infrared region is between 1650 and 3300° C. However, most commercial sources of infrared heat operate in the middle section of the infrared region. Tests were conducted at this laboratory by using infrared heaters with a surface temperature of 926° C. They emitted approximately 75% of their output in the middle range, and peak emission occurred at 2.5μ

The frequencies for microwave heating are controlled in the United States by the Federal Communications Commission and only four (915, 2,450, 5,500, and 22,125 MHz) are permitted for industrial, scientific, and medical uses [1]. Of these frequencies, 2,450 MHz (or 2.45 GHz) has been most commonly used for heating.

The use of convection heating for insect control will also be discussed.

INFRARED RADIATION: Many stored-grain commodities such as wheat, corn, and rice are heated during the drying or manufacturing process. Infrared heating is often used in these processes since this energy can be readily absorbed by the commodities.

Rice and wheat can be successfully treated with infrared energy for insect control because the temperature of these two cereal grains can be increased to 80° C without damage to either their baking or milling qualities [2]. Loaf volume of bread baked from heated wheat was found [3] to decrease at 65° C, and especially at 80° C, but the head yield of rice was increased by these high temperatures [4]. Other commodities such as corn (maize), milo, or oil crops such as cowpeas, peanuts, or pecans are damaged if their temperatures are increased to 65° C by using infrared radiation at 2.5μ.

In earlier studies [5], both grain and insects were heated by radiant energy from infrared lamps, but in recent years the energy from gas-fired infrared heaters has been used to control stored-product insects. When the latter technique was used, the lesser grain borer, *Rhyzopertha dominica* (F.), proved to be more resistant to 68° C than either the rice weevil, *Sitophilus oryzae* (L.), or the Angoumois grain moth, *Sitotroga cerealella* (Olivier) [6]. However, mortalities of 99% or more were obtained at 63° C with 12 species of adult stored-product insects [7].

Infrared radiation exerts a significantly greater control of the older stages of lesser grain borers infesting soft red winter wheat, in contrast, younger rice weevils were significantly more sensitive than were the older stages [8]. When Angoumois grain moths infesting hard red winter wheat were treated with infrared radiation to obtain a 50% reduction in the moth population, the mature larvae and prepupal stages of development were found to be more susceptible than the other stages of development [9] and, the egg stage (0-2 days) was more resistant than any other stage. Adult mortalities of 99.7% for rice weevils and 99.3% for lesser grain borers were obtained by treating bulk quantities of soft red winter wheat through a 926° C infrared heater at 2.5μ to obtain a grain temperature of 48.6° C [10]. About 75% of the immature rice weevils and 83% of the immature lesser grain borers were killed when the infested wheat was heated to 48.6° C and cooled to an ambient temperature of 26° C. When the heated wheat was retained in a large container, the temperature decreased to 43.3° C after 24 hours and to 37.8° C after 48 hours. At these temperatures, mortalities greater than 99.8% were obtained with the immature rice weevils and 93% mortality was obtained with the immature lesser grain borers. The lesser grain borers were more resistant than rice weevils to this prolonged exposure to high temperature.

There were apparent differences in the susceptibility of pre-emergent adults and immature stages of rice weevils in wheat treated at 48.6° C and cooled immediately. The reduction in adult emergence from heated wheat was 92% of that in the control after 2 weeks, indicating a marked susceptibility in pre-emergent adults, pupae, and last (late)-instar larvae; 55% after 3-4 weeks, indicating lower susceptibility in 2nd to 4th-instar larvae; and 8% after 5 weeks, indicating a tolerance of eggs and 1st-instar larvae.

The pattern of emergence was not as pronounced for the lesser grain borer. Lesser grain borers that survived a 24-hour exposure to 48.6° C emerged before the untreated insects, but those surviving a 48-hour exposure emerged after the untreated insects. Thus exposures to high temperature during a 48-hour period delayed the rate of development of the lesser grain borer.

Studies were also conducted to determine whether infrared radiation adversely affected the residual toxicity of malathion. No degradation was detected when hard red winter wheat treated with malathion at 8 ppm was exposed to infrared radiation to obtain a grain temperature of 65° C.

Recently infrared technology has developed considerably as a result of increased emphasis on space applications. These new ideas and equipment may be useful in detecting infestations and also in controlling insects that infest our food.

MICROWAVE RADIATION: The potential of microwave energy to control insects has been recognized for many years. When microwave energy is absorbed by the commodity, it is converted to heat by inter- and intra-molecular quantum effects.

In our tests with Angoumois grain moths, rice weevils, and lesser grain borers, the older larvae and pupae were more resistant to microwave energy than either the young larvae or eggs [8,11]. However, most internal-feeding insects that infest stored grain can be controlled with temperatures of 65° C produced by microwaves, and these exposures do not damage germination if wheat moisture content remains below 14% [12]. Cowpea weevils, *Callosobruchus maculatus* (F.), infesting black-eyed peas are an exception. Both larvae and pupae can survive a peak temperature of 76.7° C but germination is reduced 42% at this temperature.

Either microwave or infrared heat treatments of grain can control internal and external insect infestations, but microwave energy requires a higher temperature to produce a given mortality. In tests with soft red winter wheat infested with rice weevil and treated at 54° C, an average 13% more of the immature rice weevils, 76% more of the adults, and 56% more of the F_1 progeny of adults emerging from treated wheat were controlled with infrared radiation than were controlled with microwave energy [8].

ENTOMOLOGICAL ASPECTS OF HIGH AIR TEMPERATURES: Temperature is one of the important physical factors that affect the growth and development of insects, and it can be effectively utilized in controlling all stages of insects that infest our stored commodities. During the early part of this century, a method was developed whereby hot air recirculated from steam radiators was used to heat flour mills to temperatures ranging from 49 to 51° C for 10 to 12 hours to control insects [13]. This method was found to be effective and inexpensive, and the heat had no deleterious effect on the baking qualities of the treated flour thus, if the surface temperature of bakery products reached 60 to 66° C, the effects of oven heat were comparable to those of infrared heat in controlling all life stages of the three test species of insects [14].

Humidity may also be a limiting factor in insect survival during exposure to elevated temperatures. For example, the effect of exposure to high temperatures for short periods (1 hour or less) may be less severe if the air is dry than if the air is moist. However, the effect is reversed if exposure last 24 hours or more and then desiccation may be a major factor in insect mortality [15]. Tests were conducted to determine the effects of 4-day exposures during oviposition of the adult rice weevil and lesser grain borer in soft red winter wheat to temperatures of 39° C or 43° C at various RH's. Ninety-nine percent or more control of all stages of the rice weevil was obtained at 39° C and 60% RH, but a temperature of 43° C and 50% RH were required for comparable control of the lesser grain borer [16].

The pecan weevil larvae, *Curculio caryae* (Horn), that infest inshell pecans appear to be highly resistant to a temperature of 5° C but cannot tolerate temperatures of 43° C or more for 24 hours. No significant changes in lipid content or flavor occurred at these elevated temperatures even when pecans were treated 24 hours at 43° C and stored 5 months. Other stored-product insects such as the Indian Meal moth, *Plodia interpunctella* (Hubner), cannot withstand a temperature of 43° C for 25 hours or more.

Stored-product insects can be controlled by high temperatures produced by infrared or microwaves, and there are no adverse effects on quality if the commodity is returned to 27° C or less immediately after treatment.

EFFECT OF HIGH TEMPERATURE ON WHEAT AND FLOUR: If heat from infrared or microwave treatments could be retained, then lower temperatures might be used in treatment. Tests were conducted to determine both the reproductive potential of the rice weevil and the milling, flour analysis, physiochemical, and baking qualities of soft red winter wheat exposed to a temperature of 49° C at 50, 60, or 70% RH during 1 and 2 months of storage. Samples stored at an ambient temperature of approximately 27° C for 1 or 2 months were apparently not affected in any significant manner, and the data are similar to those obtained with the untreated wheat stored at 27° C and 60% RH. All stages of the rice weevil were killed by 1 month of storage at 49° C and RH's of 50, 60, or 70%; also, wheat characteristics appeared to have remained essentially unchanged except for a higher ash content after milling. Since flour yield did not show significant changes with treatment, a qualitative effect seems to have been induced in the separation of bran from the endosperm.

On the other hand, flour from wheat stored at 49° C did change color especially after 2 months. Flours from grain stored for 1 month showed a reddish or brownish discoloration, while those from wheat stored for 2 months were distinctly reddish, an attribute that detracted from quality. Although bread was not baked from this flour, the coloration would probably have an adverse effect on the bread crumb color.

The principal effect of storage of treated wheat became evident in the flour analysis. On the basis of viscosity or cookie data, wheat stored at 27° C for either 1 or 2 months did not result in flour differing significantly in quality from that of the control. Storage at 49° C for 1 month brought about significant decreases in viscosity, indication of an effect on wheat protein that seemed to be associated with relative humidity. Also the hydration properties (AWRC) of flour from wheat stored for either 1 or 2 months at 49° C were increased significantly in relation to samples stored at 27° C, and the cookie diameter was correspondingly decreased. Apparently, there is an inverse relationship between flour hydration properties and cookie spread.

Similar results were obtained in tests with patent flour stored for longer periods, 6 months to 1 year, or temperatures ranging from 32 to 43° C. However, these deleterious effects of temperature and storage were not evident in a 12% soy-fortified flour [17].

DISCUSSION: No method of insect control will handle all species of insects in all commodities, but there are a few general principles that can be applied to the use of nonionizing radiation for control of stored-product insects.

Heat can be transferred from a warm body to a cooler body by conduction, convection, and radiation. In conduction, the source of heat is in direct contact with the object that is being heated. For example, in many areas of the world, small quantities of grain are stored in various types of containers. Sometimes a large black concrete slab is used at the storage site for drying crops in the sun. If the grain is spread 1 cm or less deep on the hot dark area and exposed 20-30 minutes to the sun's rays, all forms of infestation can be controlled. Likewise, at the turn of the century, experiments showed that an air temperature of 38° C resulted in a soil-surface temperature of 61° C [18]. Therefore when infested cowpeas were exposed to sunlight on the ground and the shade temperature reached 37° C, complete control of all cowpea weevils resulted in 75 minutes. Moreover, if the infested peas were placed in a glass-covered tray, only 15 minutes were required to obtain complete mortality of all weevils [19].

Thermal energy from convection is not transferred directly from the source to the body that is being heated, it is transferred through air movement. This type of heating gives inefficient insect control because of the double transfer of heat from the source to the air to the commodity. However, heat convection was used with some success for insect control in flour mills before the advent of insecticides. Even today this principle is used in drying grain before it is stored. All methods of grain drying should be investigated to determine the extent of insect control achieved with field-infested grain.

Engineers are using solar radiation to heat our buildings so this principle could perhaps be utilized for insect control in stored commodities. Thus the pipes that circulate the warm water could be placed inside present grain storage facilities. The recirculated warm dry air would increase grain temperature so as to keep the insects out of the stored grain and the grain dry, which would prevent development of molds. Storage facilities could be constructed near power plants where heat is a waste product.

Heat transfer by radiation is less dependent on the nature of the medium because radiation energy from the microwave or infrared source is changed into electromagnetic radiation, absorbed by the grain, converted back into thermal energy. If this thermal or radiant energy is applied to static or moving grain, the commodity temperature is increased, and the insect infestation can be controlled. However, only clean grain (chaff and dust free) should be treated with gas-fired infrared heaters because of the fire hazard. There is no fire hazard due to excessive grain dust if the grain is heated by microwave radiation.

Insects can therefore be controlled with infrared, microwave, or heat, and these nonchemical control methods should be utilized more fully in the future. Research should therefore be directed toward improving the efficiency of transfer of radiant energy to infested food commodities to lessen our dependence on chemicals.

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