MAJOR AND TRACE ELEMENTS AS BIOPREDICTORS OF RADIATION-INDUCED INSECT STERILITY[1]

R. LEVY[2], H. L. CROMROY[2], AND J. A. CORNELL[3]

ABSTRACT

Multiple regression models of 11 species of adult insects representing the orders Anoplura, Coleoptera, Diptera, and Lepidoptera indicated that total body concentrations of several major and trace elements could be used as a bioindicator or biopredictor of radiation-induced insect sterility on a species level. There was a particularly high correlation between total body major and trace element content and irradiation-induced insect sterility in a group of stored-product insects that had similar feeding preferences (i.e., laboratory diets of grain and/or flour).

A statistical model based on insect total body Cu and K/Mg ratio was highly effective in estimating or predicting the radiosterilization doses for several species of stored product insects feeding primarily on grain and/or flour.

Total body concentrations of several major and trace elements (cations) have been shown to be correlated to the acute (LD50/24 hr) radiosensitivity of stored product beetles, cockroaches, and blood feeding insects (Levy et al. 1973). Simple regression analyses indicated that Cu or Cu/Fe ratio, K, and Mg were the most effective biological predictors or indicators of acute radiation mortality for the 3 groups respectively. Additional research utilizing multiple regressison analyses indicated the interelement dependence of Na with K (i.e. Na + K) and Mg (i.e. Na + Mg) in formulating predictor models for estimating the acute radiation mortality of cockroaches and blood feeding insects respectively (Levy et al. in press).

The dietary and metabolic importance of major and trace elements have been briefly reviewed by Levy and Cromroy (1973). Englemann (1970) presented an excellent review showing the importance of dietary concentrations of Zn, Fe, K, Mg, Na, and Cu in the reproductive physiology of adult and immature insects.

The aim of this research was to determine whether total body concentrations of several major and trace elements can be used as an effective biological indicator or predictor of radiation-induced sterility on a species level.

Predictor equations could, therefore, be used to expedite the procedures involved in determining a species-specific radiosterilization dose for insect control, e.g. in a sterile-male release program. Such information could also be used to evaluate insect and other biological imbalances produced in a post-nuclear attack environment.

METHODS AND MATERIALS

The total body concentration of Cu, Fe, K, and Mg in 11 species of adult insects representing the orders Anoplura, Coleoptera, Diptera, and

---

[1] Florida Agricultural Experiment Station Journal Series No. 5095.

[2] Department of Entomology and Nematology, University of Florida, Gainesville, Florida 32611.

[3] Department of Statistics, University of Florida, Gainesville, Florida 32611.

Lepidoptera were obtained from the atomic absorption spectrophotometric data of Levy and Cromroy (1973). Sterilization doses for adult insects were obtained from the radiation literature (International Atomic Energy Agency Bibliographical Series Nos. 9(1963), 15(1965), 24(1967); Stern (1969) from samples of mixed sexes or obtained separately for males and females and averaged to give a general sterilization dose for an insect species population. The sterilization dose for a species was defined as that dose in rads (radiation absorbed dose) of x or gamma radiation required to induce 99.9-100.0% sterility in the irradiated insects. Sterilization doses obtained in units of R (Roentgen) were converted to rads by multiplying by a conversion factor of 0.93.

Statistical analyses consisted of fitting multiple regression models using the method of least squares (Draper and Smith 1966). These analyses were based on the straight line equation, $y = b_0 + b_1(X_1) + b_2(X_2)$, where $y =$ *estimated* or *predicted* radiosterilization doses in rads, $b_0 =$ constant, $b_1 ... b_2 =$ estimate or measure of the strength of $X_1 ... X_2 =$ total body concentration of a specific element or ratio of elements in parts per million (ppm).

To test the strength of a predictor equation, the coefficient of multiple determination (R^2) and F-statistic (F) were calculated for each model. F-test significance at the 0.05 level was indicated for each model. The standard error (SE) for each predicted or estimated radiosterilization dose was also determined.

Results and Discussion

Results from multiple regression analyses indicated that a model representing the ratio of 2 trace (Cu/Fe) and 2 major (K/Mg) elements was the most effective indicator or predictor of radiation-induced sterility for a wide range of insect species (Table 1).

Relationships between trace (Cu/Fe) and major (Na & Mg, Na & K) elements have been shown to be useful in estimating or predicting the radiosensitivity of stored product beetles, cockroaches, and blood feeding insects (Levy et al. 1974). A biological relationship has been shown between Na and Mg, hence, it could be conjectured that a relationship exists between K and Mg in insects (Chapman 1969).

Although the predictor equation (Table 1) was significant at the 0.05 level, it only accounted for 75% (i.e. $R^2 = 0.7478$) of the observed radiosterilization doses. This was assumed to be due primarily to variations in diet, since Levy et al. (1973) have shown a relationship between radiosensitivity and insect dietary (i.e. the total body concentration of major and trace elements accumulated from an insect diet). Additional variations between the observed and predicted radiosterilization doses were presumed to be due to phylogenetic relationships, body weight and size, and physical activity (Menhinick and Crossley 1969). Therefore, the insect species were subdivided and an analysis made of a group that had similar feeding preferences, i.e., stored-product insects fed grain and/or flour.

Multiple regression analyses of 7 species of stored product insects representing the orders Coleoptera and Lepidoptera suggested an interelement dependence of major and trace elements in formulating effective models for predicting insect radiosterilization (Table 2). The data indicated that total body concentrations of several biologically active trace (Cu) and major (K/Mg) elements (cations) could be used as an excellent biological indicator of predictor of radiation-induced sterility of stored product insects

TABLE 1. TRACE AND MAJOR ELEMENTS AS A GENERAL BIOPREDICTOR OF RADIATION-INDUCED STERILITY FOR A WIDE VARIETY OF INSECT SPECIES. [$y = -0.2806 + 18.4886\,(Cu/Fe) + 0.6291\,(K/Mg)$]*.

Species	Total body Cu/Fe (ppm)	Total body K/Mg (ppm)	Observed radiosterilization dose (Krad)	Predicted radiosterilization dose (Krad) ±SE
Sitophilus oryzae (L.)	0.3556	5.2233	7.00	9.58±1.69
Tribolium castaneum (Herbst)	0.3542	10.3593	9.50	12.79±1.41
Trogoderma inclusum LeConte	0.2192	10.8832	12.81	10.62±1.14
Oryzaephilus surinamensis (L.)	0.2857	11.1229	15.30	12.00±1.14
Lasioderma serricorne (F.)	0.0676	18.3887	16.00	12.54±1.63
Phthorimaea operculella (Zeller)	0.4694	19.1466	22.32	20.44±2.39
Cadra cautella (Walker)	0.2500	28.3333	23.50	22.17±2.08
Epilachna varivestis Mulsant	0.2235	10.1813	11.16	10.26±1.18
Drosophila melanogaster Meigen	0.0593	30.4153	14.97	19.95±2.35
Pediculus humanus humanus L.	0.0468	12.1376	9.30	8.22±1.93
Hippelates pusio (Loew)	0.2267	6.4167	4.65	7.95±1.50

*$R^2 = 0.7478$; F-test ($F = 11.8617$) significant at the 0.05 level.

TABLE 2. TRACE AND MAJOR ELEMENTS AS A BIOPREDICTOR OF RADIATION-INDUCED STERILITY OF STORED PRODUCT INSECTS*. [$y = -6.3784 + 0.5199\,(Cu) + 0.8723\,(K/Mg)$**.]

Species	Total body Cu (ppm)	Total body K/Mg (ppm)	Observed radiosterilization dose (Krad)	Predicted radiosterilization dose (Krad) +SE
Sitophilus oryzae	16	5.2233	7.00	6.50±0.97
Tribolium castaneum	17	10.3593	9.50	11.50±0.62
Trogoderma inclusum	16	10.8832	12.81	11.43±0.64
Oryzaephilus surinamensis	22	11.1229	15.30	14.76±0.81
Lasioderma serricorne	14	18.3887	16.00	16.94±0.62
Phthorimaea operculella	23	19.1466	22.32	22.28±1.16
Cadra cautella	9	28.3333	23.50	23.02±1.23

*Diet consisted mainly of flour and/or grain.
**$R^2 = 0.9666$; F-test ($F = 57.8278$) highly significant at the 0.05 level.

on a species level when insects were subdivided into a general feeding group based on laboratory diets consisting mainly of grain and/or flour. Levy et al. (1973) have shown the importance of Cu in estimating or predicting the acute radiosensitivity of stored product beetles.

The removal of Fe from the stored product insect model seemed to eliminate an erroneous feeding variable accumulated from an insect diet not having mineral levels comparable with a diet of grain and/or flour. This subsequently increased the prediction capability by significantly (i.e. $R^2 = 0.9666$) decreasing the variation between the observed and predicted radiosterilization doses.

These data suggest the physiological importance and interaction of certain trace and major elements (cations) in the mechanism(s) involving the radiosensitivity of insects. In addition, the stored product insect grouping was presumed to have reduced phylogenetic variations, as well as variations in body size, weight, and physical activity which have been shown to be related to insect radiosensitivity.

ACKNOWLEDGEMENTS

This research was partly supported by NIH Training Grant No. 1T01A100383-01 from the National Institute of Allergy and Infectious Diseases.

LITERATURE CITED

Chapman, R. F. 1969. The Insects: Structure and Function. American Elsevier Publishing Co., Inc. 819p.

Draper, N. R., and H. Smith. 1966. Applied regression analysis. John Wiley & Sons, Inc., N.Y. 407p.

Englemann, F. 1970. The physiology of insect reproduction, Vol. 44. Pergamon Press, N.Y. p. 117-118.

Levy, R., and H. L. Cromroy. 1973. Concentration of some major and trace elements in forty-one species of adult and immature insects determined by atomic absorption spectroscopy. Ann. Ent. Soc. Amer. 66:523-26.

Levy, R., H. L. Cromroy, and J. A. Cornell. 1973. Major and trace elements as bioindicators of acute insect radiosensitivity. Radiat. Res. 56:130-39.

Levy, R., H. L. Cromroy, and J. A. Cornell. 1974. Multi-elemental models for estimating the acute radiosensitivity of cockroaches and blood feeding insects. Fla. Ent. 57:43-46.

Radioisotopes and Ionizing Radiations in Entomology, Vol. I, (1950-1960), Bibliographical Series No. 9, p. 371. International Atomic Energy Agency, Vienna, 1963.

Radioisotopes and Ionizing Radiations in Entomology, Vol. II, (1961-1963), Bibliographical Series No. 15, p. 435-37. International Atomic Energy Agency, Vienna, 1965.

Radioisotopes and Ionizing Radiations in Entomology, Vol. III, (1964-1965), Bibliographical Series No. 24, p. 326-33. International Atomic Energy Agency, Vienna, 1967.

Stern, V. M. 1969. Insect pests of major food crop, their reinvasion potential and the effects of radiation on arthropods. OCD Work Unit No. 3145B, University of California.