# MAPPING SULFURYL FLOURIDE QUARATINE CONTROL OF *AMYELOIS TRANSITELLA* USING MULTIVARIATE MODELING

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Data indicates that there is more variability in navel orange worm (NOW), *Amyelois transitella*, egg mortality with sulfuryl fluoride under vacuum (100 mm Hg) relative to atmospheric pressure (760 mmHg). This suggests that the concentration and time cross-product alone is not an accurate predictor of NOW egg mortality; the effect of vacuum has to be considered. Confirmatory fumigations, with walnut commodity, support this interpretation. At 760 mmHg, 32 mg/L exposures over 24 h in 12 chambers resulted in complete mortality of 1882 NOW. At 100 mmHg, however, a single NOW egg out of 2039 survived 112 mg/L exposure for 4 h. The individual and interactive effect(s) of pressure, temperature, time, and sulfuryl fluoride dose on NOW egg mortality are quantitatively delineated; a multifactorial experiment was generated and the results were analyzed using Design Expert 7.0 (Stat-Ease, Inc.). A four-factor central composite design was employed, which contained five levels of the four factors, $x_1$–$x_4$, and six center-point replicates. Conditions of temperature, duration, and pressure were chosen to accommodate, or span, those applicable to standard industrial practice, at least with respect toward analogous methyl bromide protocols.

| *Factor (original units)* | *Factor levels* | | | | |
|---|---|---|---|---|---|
| | $-\alpha$ | -1 | 0[a] | 1 | $\alpha$ |
| $x_1$: dose (mg/L) | 0 | 24 | 48 | 72 | 96 |
| $x_2$: temp (°C) | 5 | 10 | 15 | 20 | 25 |
| $x_3$: duration (h) | 1 | 12 | 24 | 36 | 48 |
| $X_4$: pressure (- inch. Hg) | 0 | 7 | 14 | 21 | 28 |

[a] level 0 = center point

The design involved a total of 30 experiments, which were run in a randomized order in three different time blocks. The modeled response(s) ($y$) was insect survivability. A full second-order quadratic expression was chosen that contained 15 parameters including linear and quadratic dependencies on each factor and all possible two-factor interactions:

$$y = \beta_0 + \beta_1 x_1 + \beta_{11} x_1^2 + \beta_2 x_2 + \beta_{22} x_2^2 + \beta_3 x_3 + \beta_{33} x_3^2 + \beta_4 x_4 + \beta_{44} x_4^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{23} x_2 x_3 + \beta_{24} x_2 x_4 + \beta_{34} x_3 x_4$$

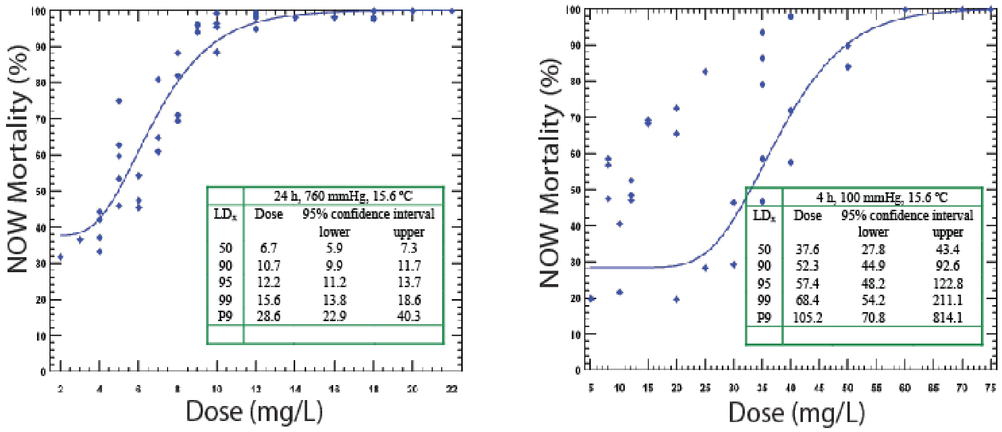
The parameters of this full second-order model include: $\beta_0$, a constant or offset term; $\beta_1$, $\beta_2$, $\beta_3$, $\beta_4$ estimate the linear effects of the factors; $\beta_{11}$, $\beta_{22}$, $\beta_{33}$, $\beta_{44}$ estimate the quadratic (curvature) effects of the factors; and $\beta_{12}$, $\beta_{13}$, $\beta_{23}$, $\beta_{24}$, $\beta_{34}$ estimate the interaction effects between every pair of two factors. The following equation represents the optimized model, which predicted NOW egg survivability (y) with a $r^2$ of 0.89.

$$y^{-1/2} = 3.16 + 0.57x_1 - 0.37x_1^2 - 0.055x_2 + 0.004x_2^2 + 0.74x_3 - 0.37x_3^2 + 0.11x_4 \\ + 0.004x_4^2 - 0.18x_1x_2 + 0.47x_1x_3 + 0.085x_1x_4 + 0.082x_2x_3 + 0.012x_2x_4 - 0.17x_3x_4$$

The coefficients ($\beta_x$) were tested for significance against the null hypothesis ($\beta_x = 0$), that the factor was unimportant in determining survivability. At the 95% level of confidence, digestion efficiency depended linearly on the dose ($\beta_1$) and duration ($\beta_3$), quadratically on dose ($\beta_{11}$) and duration ($\beta_{33}$), and on the interaction between dose-temperature ($\beta_{12}$) and dose-duration ($\beta_{13}$). The final equation shows the optimized simplified model:

$$y^{-1/2} = 3.16 + 0.57x_1 + 0.74x_3 - 0.37x_1^2 - 0.37x_3^2 - 0.18x_1x_2 + 0.47x_1x_3$$

Indeed, the predicted $r^2$ of the simplified model improved to 0.92. It is important to note that the coefficient to describe dose-temperature interaction ($\beta_{12}$) has a negative value that translates into increased survivability of NOW eggs. Therefore, when targeting NOW egg mortality in winter and late fall at relatively lower temperatures, compensation is required via higher fumigation doses or longer exposure times. The final equation serves as a valuable and practical utility to industry, as they can be used to predict NOW egg survivability during sulfuryl fluoride fumigations of stored-product dried fruit and nuts. Generally speaking, it can be used as a predictive tool for ensuring that targeted mortality levels are achieved during individual fumigation events. This should be particularly useful when probit 9 quarantine levels are required to move commodity through foreign trade and marketing channels.



| | 24 h, 760 mmHg, 15.6 °C | | |
|---|---|---|---|
| LD$_x$ | Dose | 95% confidence interval | |
| | | lower | upper |
| 50 | 6.7 | 5.9 | 7.3 |
| 90 | 10.7 | 9.9 | 11.7 |
| 95 | 12.2 | 11.2 | 13.7 |
| 99 | 15.6 | 13.8 | 18.6 |
| P9 | 28.6 | 22.9 | 40.3 |

| | 4 h, 100 mmHg, 15.6 °C | | |
|---|---|---|---|
| LD$_x$ | Dose | 95% confidence interval | |
| | | lower | upper |
| 50 | 37.6 | 27.8 | 43.4 |
| 90 | 52.3 | 44.9 | 92.6 |
| 95 | 57.4 | 48.2 | 122.8 |
| 99 | 68.4 | 54.2 | 211.1 |
| P9 | 105.2 | 70.8 | 814.1 |

Insecticidal efficacy, tabulated below at lethal dose ($LD_x$) and probit 9 (P9, $LD_{99.9986}$) quarantine levels, of sulfuryl fluoride eggs of NOW.