EFFECTS OF MINERAL SALTS IN THE DIET OF THE MEDITERRANEAN FLOUR MOTH, *ANAGASTA KUEHNIELLA* (ZELLER)[1]

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ABSTRACT

Thirty-two different mineral salts were added individually to a diet of whole wheat flour to investigate their effects on population numbers, times of development and longevity of the Mediterranean flour moth, *Anagasta kuehniella* (Zeller). The effect upon the time of development varied from inhibitory to no effect to very stimulatory. All tested salts inhibited the egg-laying in P and F_1 generations but egg laying completely stopped only with all the concentrations of sodium nitrate, $NaNO_3$ in the diet of the P generation. No single anion or cation was found which would strongly affect this stored-product insect. The effect of each salt at each concentration was found to be different.

Key Words: Mineral salts, diets, Mediterranean flour moth, *Anagasta kuehniella*.

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INTRODUCTION

In 1964, Majumder and Bano reported the toxic effects of calcium phosphate salts to insect pests of stored grain. The research has been followed by Press et al. 1972, Majunder 1974, Highland 1975, Baker et al. 1976, Boczek and Ignatowicz 1978, Ignatowicz and Boczek 1978, and Kruk et al. 1983 on the effects of these and other mineral salts on insect and mite development. Research has shown that some of the mineral salts examined, which are commonly added to foods, e.g., tricalcium phosphate, ($Ca_3(PO_4)_2$), will affect the development of some stored-product pests. The exact mechanisms involved in this adverse effect are not fully understood.

Depending upon the adequacy of the treated food as an insect diet, these mineral salts have prevented or suppressed the development of the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.); the red flour beelte, *Tribolium castaneum* (Herbst); the confused flour beetle, *T. confusum* Jacquelin du Val; the

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rice weevil, *Sitophilus oryzae* (L.); the almond moth, *Cadra cautella* (Walker); the cowpea weevil, *Callosobruchus maculatus* (F.); the flat grain beetle, *Cryptolestes pusillus* (Schoenherr); and the mold mite, *Tryophagus putrescentiae* (Schrank).

This paper presents an evaluation of a series of mineral salts for their value in the suppression of population development in the Mediterranean flour moth, *Anagasta kuehniella* (Zeller).

METHODS AND MATERIALS

Thirty-two salts (Table 1) were used in concentrations of 1.0, 2.0, and 3.0% by weight. All test insects were from the Agricultural University of Warsaw's stock colonies where they are maintained at 25 to 30°C and 75 to 85% RH. Diets were prepared by grinding whole grain wheat to a particle size of 220 μm of less. Salts to be tested were thoroughly mixed with the desired amount of ground wheat. Tests were established by placing 40 g of this ground wheat-salt mixture into 370 ml glass jars and introducing 100 1-d-old larvae. All tests were conducted at 26°C and 75% RH. Each test was replicated three times. Mean developmental times to adulthood were calculated by dividing the number of development days by the number of moths secured from 100 larvae. Observations on the fecundity were made using 25 individual pairs of adults and egg viability was established using all the eggs laid by females of the 25 pairs.

For the analyses of the data, numbers were transformed as follows: total number of progeny tested — $y = \log(x + 1)$; for egg viability — Bliss'es transformation; for the developmental time — $y = \sqrt{x}$. Transformed data were statistically treated by analysis of variance. Significance of differences was tested with Duncan's multiple range test ($P = 0.05$).

RESULTS AND DISCUSSION

Data dealing with the effect of these salts on mean developmental time for the P and F_1 generations of *A. kuehniella* are presented in Table 1. It can be seen from these data that many salts extended the developmental time of P generation but some also shortened it. The effect of the salts was variable, e.g., some carbonates: ammonium carbonate ($(NH_4)_2CO_3$) and potassium carbonate (K_2CO_3); phosphates: ammonium dihydrogen phosphate ($NH_4H_2PO_4$) and potassium dihydrogen phosphate (KH_2PO_4); and the chloride and sulfate: magnesium chloride hexahydrate ($MgCl_2{\cdot}6H_2O$) and magnesium sulfate heptahydrate ($MgSO_4{\cdot}7H_2O$) stimulated development, particularly at the lower salt concentrations. Other salts, e.g., calcium carbonate ($CaCO_3$), sodium bicarbonate ($NaHCO_3$), magnesium carbonate ($MgCO_3$), potassium sulfate (K_2SO_4), potassium nitrate (KNO_3), magnesium nitrate ($Mg(NO_3)_2$), sodium sulfate (Na_2SO_4), and ammonium nitrate (NH_4NO_3) were inhibitory to varying degrees. At higher salt concentrations, the developmental time was longer for tricalcium phosphate ($Ca_3(PO_4)_2$) and potassium dihydrogen phosphate (KH_2PO_4), as might be expected, but the converse occurred with potassium hydrogen phosphate (K_2HPO_4) and magnesium hydrogen phosphate trihydrate ($MgHPO_4{\cdot}3H_2O$).

The developmental time of the F_1 generation was also prolonged by the action of some salts and shortened by others. The time was shortened by potassium carbonate (K_2CO_3), potassium dihydrogen phosphate (KH_2PO_4) and magnesium

Table 1. Developmental time (days) for *Anagasta kuehniella* P and F_1 generations reared on diets mixed with mineral salts at three concentrations (average of 3 replicates).

	P generation concentration (%)			F_1 generation concentration (%)		
Salt	1	2	3	1	2	3
Control	54.1 b*	54.1 b	54.1 b	51.1 b	51.1 b	51.1 b
$CaCl_2$ (calcium chloride)	55.4 b	57.1 b	61.2 c	54.9 b	53.0 b	84.1 f
$CaCO_3$ (calcium carbonate)	55.5 b	60.4 c	60.5 c	47.1 a	46.5 a	45.7 a
$CaHPO_4$ (calcium hydrogen phosphate)	55.7 b	55.2 b	–			
$Ca(H_2P_4)_2{\cdot}H_2O$ (calcium dihydrogen phosphate monohydrate)	48.2 a	52.6 b	54.4 b			
$Ca_3(PO_4)_2$ (tricalcium phosphate)	49.1 a	58.9 c	80.5 e			
$Ca(NO_3)_2$ (calcium nitrate)	58.8 c	58.5 c	62.4 c	49.0 a	53.4 b	60.5 d
$CaSO_4$ (calcium sulfate)	57.2 c	59.3 c	48.5 a	46.4 c	79.6 e	53.0 b
KCl (potassium chloride)	51.6 b	53.9 b	53.4 a			
K_2CO_3 (potassium carbonate)	46.3 a	47.9 a	51.7 a	46.2 a	53.5 b	52.1 b
K_2HPO_4 (potassium hydrogen phosphate)	62.7 d	54.4 b	50.6 a	49.3 a	48.4 a	49.4 b
KH_2PO_4 (potassium dihydrogen phosphate)	49.3 a	57.4 b	60.2 c	47.1 a	47.4 a	48.2 a
KNO_3 (potassium nitrate)	57.3 c	53.8 b	58.0 b	58.5	–	–
$KHSO_4$ (potassium bisulfate)	49.0 a	53.4 b	56.1 b	51.8 b	50.0 a	53.4 b
K_2SO_4 (potassium sulfate)	58.4 c	56.7 b	57.0 b	58.3 c	59.4 c	59.4 d
$MgCl_2{\cdot}6H_2O$ (magnesium chloride hexahydrate)	45.7 a	48.5 a	52.3 a	46.4 a	48.8 a	55.2 c
$MgCO_3$ (magnesium carbonate)	72.4 e	68.2 d	48.6 a	49.09 a	48.3 a	45.5 a
$MgHPO_4{\cdot}3H_2O$ (magnesium hydrogen phosphate trihydrate)	63.8 d	58.4 c	55.7 b	69.6 d	58.5 c	58.8 c
$Mg(NO_3)_2$ (magnesium nitrate)	65.7 d	56.3 b	62.6 c	47.9 a	48.5 a	52.5 b
$MgSO_4{\cdot}7H_2O$ (magnesium sulfate heptahydrate)	47.7 a	48.4 a	50.4 a	53.0 b	58.0 c	58.4 c

Table 1. Continued.

Salt	P generation concentration (%)			F_1 generation concentration (%)		
	1	2	3	1	2	3
NaCl (sodium chloride)	60.5 c	64.7 d	60.1 c	53.2 b	50.8 b	52.7 b
Na_2HPO_4 (sodium hydrogen phosphate)				58.4 c	69.9 d	61.7 d
$NaHCO_3$ (sodium bicarbonate)	58.2 c	52.2 b	53.8 b			
$NaH_2PO_4 \cdot H_2O$ (sodium dihydrogen phosphate monohydrate)	54.2 b	54.4 b	48.3 a	72.0 d	46.7 a	60.9 d
$Na_3PO_4 \cdot 12H_2O$ (sodium phosphate duodecahydrate)	54.3 b	52.9 b	–	–	–	51.1 b
$NaNO_3$ (sodium nitrate)	61.4 c	47.9 a	60.0 c	47.8 a	51.1 b	52.1 b
Na_2SO_4 (sodium sulfate)	75.0 e	75.7 e	76.1 d	–	48.4 a	55.3 c
$(NH_4)_2CO_3$ (ammonium carbonate)	45.4 a	48.0 a	48.3 a	52.1 b	53.3 b	60.9 c
$(NH_4)_2HPO_4$ (ammonium hydrogen phosphate)	54.3 b	56.1 b	55.8 b	49.5 a	60.9 c	57.7 c
$NH_4H_2PO_4$ (ammonium dihydrogen phosphate)	48.2 a	52.3 b	–	45.5 a	50.1 a	52.6 b
$(NH_4)_3PO_4$ (ammonium phosphate)	55.7 b	52.0 b	57.5 b	46.4 a	48.7 a	51.0 b
NH_4NO_3 (ammonium nitrate)	79.2 f	50.5 a	59.9 c	47.1 a	59.6 c	62.1 d
$(NH_4)_2SO_4$ (ammonium sulphate)	47.8 a	58.9 c	56.0 b	58.9 c	–	70.0 e

* Means within a column followed with the same letter are not significantly different by Duncan's Multiple Range Test, $P = 0.05$.

chloride hexahydrate ($MgCl_2 \cdot 6H_2O$). The effect of other salts, i.e., ammonium sulfate ($(NH_4)_2SO_4$) which was stimulatory in the P and inhibitory in the F_1 generations or inhibitory in the P and stimulatory in the F_1 generations, as were sodium sulfate (Na_2SO_4), ammonium nitrate (NH_4NO_3), calcium carbonate ($CaCO_3$), sodium nitrate ($NaNO_3$), magnesium nitrate ($Mg(NO_3)_2$), magnesium carbonate ($MgCO_3$), calcium nitrate ($Ca(NO_3)_2$), magnesium carbonate ($MgCO_3$), and potassium hydrogen phosphate (K_2HPO_4).

All salts inhibited the egg laying both in the P and F_1 generations. However, only in the case of potassium nitrate (KNO_3) at the 2 and 3% levels and with 1% sodium sulfate (Na_2SO_4) were eggs not deposited in the F_1 generation (Table 2). Some salts, e.g., sodium sulfate (Na_2SO_4), potassium hydrogen sulfate ($KHSO_4$), calcium sulfate ($CaSO_4$), ammonium nitrate (NH_4NO_3), magnesium nitrate ($Mg(NO_3)_2$), potassium nitrate (KNO_3), sodium dihydrogen phosphate hydrate ($NaH_2PO_4 \cdot H_2O$), magnesium hydrogen phosphate trihydrate ($MgHPO_4 \cdot 3H_2O$), ammonium dihydrogen phosphate ($NH_4H_2PO_4$), calcium carbonate ($CaCO_3 \cdot 12H_2O$) and calcium chloride ($CaCl_2$) were very inhibitory in the P generation. Generally, the effect of most salts on egg laying was similar in the P and F_1 generations. At the higher concentrations, the effect was unpredictable.

The effect of mineral salts on egg viability was also investigated and compared (Table 3). Usually a strong decrease in fecundity was associated with some decrease in egg viability. Salts like ammonium phosphate ($(NH_4)_3PO_4$) caused small increases in egg viability in P generation in all concentrations tested. Egg viability was usually much lower in F_1 than in P generation. The greatest decrease in egg viability in the F_1 was observed for ammonium dihydrogen phosphate ($NH_4H_2PO_4$). The effect of higher concentrations was variable. In one case, with the mineral salt, sodium nitrate ($NaNO_3$), the higher the concentration in the diet the greater the egg viability in both P and F_1 generations. With other mineral salts, no such relationship was noted.

Results obtained with *A. kuehniella* differ distinctly from those for *Tryophagus putrescentiae* (Schrank) (Boczek and Ignatowicz 1978), *Tribolim confusm* Jacquelin du Val (Kruk et al. 1983), *Plodia interpunctella* (Hubner) (Press et al. 1972) and other stored-product pests (Majunder and Bano 1964). No one anion or cation showed a strong effect on the development time, fecundity or egg viability of this moth. High tolerance to high concentrations of various salts in *A. kuehniella* larvae cannot be explained except by the possibilty of increased ability to excrete these compounds.

Tricalcium phosphate ($Ca_3(PO_4)_2$), which is known as a strong suppressant for many stored-product pests, was not very effective for suppressing development in *A. kuehniella.* It extended development only at the high concentration, 3%. It did inhibit fecundity but most eggs laid were viable.

Table 2. Fecundity in P and F_1 generations of *Anagasta kuehniella* reared on diets mixed with mineral salts at three concentrations (average of 25 replicates).

	P generation concentration (%)			F_1 generation concentration (%)		
Salt	1	2	3	1	2	3
Control	180.3 e*	180.3 c	180.3 c	180.3 c	180.3 c	180.3 c
$CaCl_2$	7.0 b	40.6 a	96.5 b	38.5 a	63.4 a	90.3 a
$CaCO_3 \cdot 12H_2O$	52.8 d	73.8 b	82.6 b	55.1 b	70.7 b	83.0 a
$CaHPO_4 \cdot 2H_2O$	76.8 d	61.5 b	115.9 b	126.6 c	71.6 b	41.1 a
$Ca(H_2PO_4)_2 \cdot H_2O$	100.3 d	102.2 b	59.4 b	70.9 b	135.8 b	90.4 a
$Ca_3(PO_4)_2$	113.3 e	58.1 b	96.7 b	36.6 a	77.8 b	134.9 b
$Ca(NO_3)_2$	53.4 d	62.7 b	81.7 b	55.5 b	69.8 b	124.3 b
$CaSO_4$	25.7 c	64.6 b	62.7 b	89.6 b	84.0 b	80.8 a
KCl	95.9 d	139.9 c	106.7 b	–	–	–
K_2CO_3	96.8 d	152.8 c	74.4 b	51.2 b	64.4 a	76.8 a
K_2HPO_4	83.3 d	84.4 b	69.3 b	71.8 b	53.8 a	121.4 b
KH_2PO_4	67.7 d	119.5 b	100.4 b	98.9 b	53.8 a	59.4 a
KNO_3	78.6 d	115.9 b	77.6 b	91.5 b	0.0	0.0
$KHSO_4$	25.0 c	61.7 b	76.9 b	54.7 b	53.2 a	117.7 b
K_2SO_4	105.4 d	83.8 b	117.5 b	98.4 b	146.7 b	133.1 b
$MgCl_2 \cdot 6H_2O$	54.2 d	43.2 a	67.9 b	82.4 b	44.2 a	128.5 b
$MgCO_3$	81.8 d	89.9 b	76.8 b	73.4 b	30.5 a	64.2 a
$MgHPO_4 \cdot 3H_2O$	60.7 d	123.9 c	94.0 b	19.5 a	107.8 b	126.9 b
$Mg(NO_3)_2$	65.4 d	72.9 b	86.8 b	36.7 a	42.2 a	76.9 a
$MgSO_4 \cdot 7H_2O$	69.6 d	29.6 a	101.2 b	78.7 b	113.2 b	113.7 b

NaCl	119.1 e	65.9 b	121.4 b	50.6 b	37.2 a	134.5 b
$NaH_2PO_4 \cdot H_2O$	–	–	–	124.3 c	93.4 b	65.2 a
$NaHCO_3$	132.7 e	151.0 c	24.3 c	–	–	–
$NaH_2PO_4 \cdot H_2O$	60.2 d	63.3 b	85.5 b	–	–	–
$Na_3PO_4 \cdot 12H_2O$	89.2 d	119.3 b	–	–	–	–
$NaNO_3$	107.2 d	157.3 c	93.3 b	25.0 a	43.6 a	57.4 a
Na_2SO_4	2.1 a	34.2 a	72.5 b	0.0	55.7 a	96.7 b
$(NH_4)_2CO_3$	87.7 d	69.8 b	58.0 b	138.0 c	132.4 b	70.0 a
$(NH_4)_2HPO_4$	75.2 d	77.6 b	47.3 a	51.9 b	88.7 b	101.0 b
$NH_4H_2PO_4$	65.1 d	68.1 b	67.9 b	22.9 a	88.4 b	66.2 a
$(NH_4)_3PO_4$	130.7 e	89.1 b	127.6 c	45.7 b	76.8 b	48.1 a
NH_4NO_3	60.9 d	68.9 b	93.5 b	33.8 a	70.2 b	76.1 a
$(NH_4)_2SO_4$	101.3 d	112.6 b	94.4 b	102.6 b	80.5 b	53.3 a

* Means within columns followed with the same letter are not significantly different by Duncan's Multiple Range Test, P = 0.05.

Table 3. Egg viability (%) in P and F_1 generations of *Anagasta kuehniella* reared on diets mixed with mineral salts at three concentrations (average of 25 replicates).

Concentration	1%			2%			3%		
Salt	P	F_1	(F_1 - P)	P	F_1	(F_1 - P)	P	F_1	(F_1 - P)
Control					88.9				
Inhibiting									
$NaNO_3$	80.8	37.1	−43.6 a*	89.2	57.7	−31.5 a	92.0	75.1	−17.9
$Mg(NO_3)_2$	87.6	53.1	−34.5 a	94.2	48.5	−45.6 a	85.3	74.0	−11.2
NaCl	85.1	78.5	− 6.6	66.9	55.0	−11.8	89.8	39.6	−50.1 a
$MgHPO_4$	82.1	41.5	−40.6 a	70.9	89.1	+18.2 a	75.4	88.5	+13.1
$Ca_3(PO_4)_2$	93.5	64.3	−29.1 a	58.0	51.7	+ 0.9	89.8	75.7	−14.1
$(NH_4)_3PO_4$	94.6	34.9	−59.7 a	93.3	76.1	−17.2	95.9	43.1	−52.8 a
K_2CO_3	78.7	27.3	−51.4 a	94.0	54.4	−39.6 a	49.8	73.3	+23.5
Na_2CO_3	92.8	37.9	−54.9 a	97.2	80.4	−16.8	88.6	78.1	−10.5
$MgCO_3$	75.5	69.9	− 5.6	72.4	43.0	−29.4	78.8	78.6	− 0.2
$NH_4H_2PO_4$	40.0	9.0	−31.0 a	70.3	51.3	−19.0	63.6	26.1	−27.4
$(NH_4)_2SO$	83.3	80.7	− 2.6	73.6	37.3	−36.3 a	86.7	67.6	−19.1
$MgSO_4$	63.3	23.3	−40.0 a	66.0	72.3	+ 6.4	62.0	83.8	+21.8
$(NH_4)_2HPO_4$	85.8	45.3	−40.5 a	88.4	90.2	+ 1.9	75.3	91.1	+16.9
Inhibiting and Stimulating									
$Ca(H_2PO_4)_2$	66.3	31.1	−35.2 a	86.6	83.5	− 3.1	49.6	82.1	+32.5
$KHSO_4$	48.4	83.3	+35.4 a	62.5	72.0	+10.5	96.3	45.5	−50.8 a
Stimulating									
$CaSO_4$	28.4	84.3	+55.9 a	61.8	67.7	+ 5.0	64.7	78.5	+13.8
$Ca(NO_3)_2$	79.2	76.2	− 3.0	41.6	81.9	+40.3 a	69.9	95.4	+25.5 a
$CaCl_2$	10.6	72.7	+62.1 a	68.1	62.3	− 5.8	81.8	84.9	+ 4.1
$(NH_3)_2NO_3$	75.7	69.9	− 5.8	40.1	87.4	+47.3 a	11.3	53.6	+42.3 a
Na_2SO_3	–	–	–	6.0	73.5	+67.5 a	58.3	86.5	+28.2

* Values followed by the same letter are significantly different at P = 0.05 (student-t).

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