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Optimal treatment of *Ascaridia galli*-infected chickens with salts of trace elements and a kinetic model for chicken growth

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Abstract

Data from seven experiments with *Ascaridia galli*-infected chickens have been considered. The results of treatment with neutral and basic copper, zinc and copper–zinc salts and inorganic and organic manganese compounds have been compared. An optimal therapy, containing a pure Cu basic salt ($Cu_2(OH)_3Cl$) and an organic Mn compound ($2Gly.MnCl_2.2H_2O$), is proposed to correct mineral deficiencies and pathological symptoms and to ensure lower mortality and higher gains in body weight. A mathematical model has been proposed for the growth of a healthy chicken. The relative rates for two growth stages have been determined by the model using data from mean chicken weights. The time course of the average biomass of a single *A. galli* has been theoretically derived from the same logistic equation describing chicken growth, which in turn might explain, phenomenologically, the mechanisms involved in the biomass growth of eukaryote organisms.

Introduction

Two problems have been discussed in the present paper: (i) an attempt to offer a suitable therapy formula for the treatment of chickens with ascaridiasis; and (ii) a mathematical model for the kinetics of chicken growth.

The ascarid nematode, *Ascaridia galli*, disturbs the digestion of nutrients in its avian host. Toxins of *A. galli* adversely influence enzyme systems of the intestinal mucosa and interfere with the normal absorption of nutrients in the intestine (Ackert, 1942; Vassilev *et al.*, 1973). Ascaridiasis results in a high host mortality, a decrease in body weight gain, secondary pathological symptoms and an imbalance of some trace elements such as zinc, copper, cobalt, manganese and iron. Mineral substances play an important role in the metabolism of hosts with helminthiases (Southern & Baker, 1978; Davtjan, 1982; Gabrashanska *et al.*, 1986, 1987). In poultry, copper and zinc nutrients are essential for optimal growth (Davis & Mertz, 1987), whereas manganese deficiency results in slow growth, deformation of the skeleton and changes in reproductive function (Balayan, 1982; Gabrashanska *et al.*, 1986, 1987). In order to establish more effective therapy, we performed a series of experiments on *A. galli*-infected chickens treated with: copper salts, basic and neutral (Gabrashanska *et al.*, 1993), zinc salts, basic and neutral (Galvez-Morros *et al.*, 1995), mixed salts of copper and zinc, basic and neutral (Gabrashanska *et al.*, 1999a) and manganese compounds inorganic and organic (Gabrashanska *et al.*, 1999b). In the present study we present a comparative analysis of the results of these treatments.

In our experiment with manganese compounds (Gabrashanska *et al.*, 1999b) we determined the body weight of chickens at 1, 10, 20, 30, 40, 50 and 60 days after hatching to obtain a large number of measurements, undertaken at shorter intervals for comparison with our

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previous investigations. This allowed us to correct the formula which we proposed for describing the growth of healthy chickens, as presented by a linear time course of mean chicken weight (Gabrashanska et al., 1999a). Moreover, the formula considered in the present study might be a solution of the same logistic equation proposed by us for describing the kinetics of average biomass of a single specimen of *A. galli*. In turn, our investigations have led to the proposal of a differential equation explaining, overall, phenomenologically, the growth mechanism of eukaryotes. The solutions of the so called logistic equation are in good agreement with the experimental results of the growth kinetics of both the parasite, *A. galli*, and its chicken host.

Materials and methods

Male Hisex chickens (interlinear crossbreeding of Dutch Leghorn) were divided into groups of 18, 20 or 30 and categorized as follows: group 0, control (non-infected and untreated); group 1, *A. galli*-infected and untreated; group 2, *A. galli*-infected and treated with neutral salts ($CuSO_4.5H_2O$, or $ZnSO_4.7H_2O$, or $CuSO_4.5H_2O + ZnSO_4.7H_2O$); group 3, *A. galli*-infected and treated with basic salts (pure copper salts $Cu_2(OH)_3Cl$, or pure zinc salts $Zn_5(OH)_8Cl_2.H_2O$, or mixed copper–zinc salts $Zn_{5-}xCu_x(OH)_8Cl_2.H_2O$) (Gabrashanska *et al.*, 1993, 1999a; Galvez-Morros *et al.*, 1995. In the case of treatment with manganese compounds, the following groups are considered: 0, control (healthy, untreated chickens); 1, healthy, treated with $MnSO_4.H_2O$; 2, healthy, treated with $2Gly.MnCl_2.2H_2O$; 3, infected, untreated chickens; 4, infected and treated with $MnSO_4.H_2O$; 5, infected and treated with $2Gly.MnCl_2.2H_2O$ (Gabrashanska *et al.*, 1999b).

Following starvation overnight, each chicken was orally infected by pipette with 450 embryonated *A. galli* eggs at 14 or 30 days post-hatching (p.h.).

Control and experimental chickens were reared in a vivarium and maintained on a 24 h constant light schedule in heated, thermostatically controlled, stainless steel starter batteries with raised wire floors. Feeders and water containers were also of stainless steel construction to minimize environmental contamination. All chickens were similarly fed on a conventional corn–soybean meal diet with adequate amounts of vitamins and minerals, but with no zinc and copper supplementation (US National Research Council, 1984). The chickens in the experiments with manganese compounds were fed on a corn–soybean meal diet containing 157 mg Mn^{2+} kg^{-1} food, formulated to meet the nutrient requirements of the growing chickens (US National Research Council, 1994). Chickens were allowed access to food and water *ad libitum*.

Salts were given orally and individually to each chicken in all experiments. Treatment in all cases was carried out for 5 days, followed by a 7-day interval. The first dose was given 5 days post-infection (p.i.) and the therapy quantities to each chicken were as follows: (i) pure copper salts: 8 mg Cu either in the form of neutral or basic salts; (ii) pure zinc salts: 6 mg Zn either in the form of neutral or basic salts; (iii) mixed zinc–copper salts (49.4% zinc and 11% copper): 6 mg Cu and 8 mg Zn either in the form of neutral or basic salts; (iv) manganese compounds: 0.9 g Mn^{2+} kg^{-1} food either in the form of inorganic or organic salts.

Chickens were killed after 60 days and their alimentary tract opened in a longitudinal section from the gizzard to the cloaca. The contents were washed into a 100 μm sieve, transferred to a Petri dish, examined for the presence of immature and mature *A. galli* under a microscope and the number of worms counted. Body weight gain and mortality were determined on days 30 and 60 p.i. in the experiments with Cu and Zn pure salts; 10, 30, 45, 60 and 75 p.i. in the experiment with mixed Cu–Zn salts; 10, 20, 30, 40, 50 and 60 p.h. in the experiment with manganese compounds. All data were checked for variance homogeneity using the statistical program 'Statigraphics 5.0'. A multiple range test (Duncan, 1955) was used to separate significant differences between the means.

Mathematical model

In our modelling we use the mathematical apparatus of populational kinetics. The growth kinetics of the real cell population, when interspecies compete or factors limit growth rates, is well described by the logistic equation:

$$\frac{dx}{dt} = \frac{\mu}{C} x(C - x) \qquad (1)$$

where x is the population biomass, dx/dt is the growth rate of the population and μ is the relative rate of the biomass growth. Equation 1 is known as the Verhulst-Pearl equation (Bergter, 1972; Svirezhev, 1981). It is assumed that the total biomass of the population does not exceed a stated value C. Kennedy (1975) has used equation 1 for describing of the development of parasite populations. Gabrashanska & Teodorova (1998) proposed a quantitative expression of the growth of an individual helminth, i.e. *A. galli*; also using equation 1 but in another interpretation. In the present paper we propose a similar kind of equation for birds.

The kinetic equation 1 describing cell population growth is used usually for cell aggregates of the same type. The eukaryote consists of various cells with different functions and properties. However, the total biomass in the development of a eukaryote organism changes first of all at the expense of muscle mass (i.e. muscle cells) as in the case of helminths and at the expense of muscle mass and skeleton (i.e. bone cells) as in the case of birds. Therefore, we may use, with good approximation, the method of population kinetics, as representing the 'population' of muscle and bone cells.

Experimental data on the body weight gain of the chickens can be considered as two stages within the framework of our experiment (60 days post-hatching). The growth rates of muscles and bones have been assumed almost equal. Thus the following ordinary non-linear equation for the kinetics of mean chicken weight P could be written:

$$\frac{dP}{dt} = K_1 P \frac{C_1 - P}{C_1} + K_2 P \frac{C_2 - P}{C_2} \qquad (2)$$

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under initial conditions:

$$t_0 = 0, \qquad P(t_0) = P_0 \tag{3}$$

C_1 and C_2 are maximal possible values of chicken weight for the first and second stages respectively. K_1 and K_2 are binary variables and they have the form:

$$K_1 = \mu_1 \frac{-\text{sign}(t-T)+1}{2} = \begin{array}{ll} \mu_1 & \text{at} \quad t \le T \\ 0 & \text{at} \quad t > T \end{array}$$
$$K_2 = \mu_2 \frac{\text{sign}(t-T)+1}{2} = \begin{array}{ll} 0 & \text{at} \quad t \le T \\ \mu_2 & \text{at} \quad t > T \end{array} \tag{4}$$

μ_1 ($[\mu_1] = [\text{day}^{-1}]$) and μ_2 ($[\mu_2] = [\text{day}^{-1}]$) are the relative rates of mean chicken weight gain for the first and second stages respectively. T is the moment of switching from the first to the second regime of chicken growth. Naturally, with 'switching' does not take place simultaneously as all chickens and the 'moment' T is extended to more than one day. We have made some idealization in the model and determined the most probable day on the basis of experimental data. We assume that the development of chickens is realized under the condition of substrate saturation because chickens take in a sufficient amount of feed, i.e. $\mu_i =$ const. ($i = 1, 2$).

The right side of equation 2 contains two terms, each of which in its form is similar to the expression in equation 1. However, the interpretation is substantially different in our case. Here, an increase in chicken biomass is not limited by muscle and bone cell mortality but is determined by the cell genetic programme.

So we consider the expression $(C_i - P)/C_i$ ($i = 1, 2$) as an unique coefficient which changes with the value of P:

$$\frac{C_i - P}{C_i} = \eta(P) \qquad i = 1, 2 \tag{5}$$

The value of η decreases with the increasing of P. Therefore, we can write equation 2 in the form:

$$\frac{dP}{dt} = \sum_{i=1}^{2} K_i \eta_i(P) P \tag{6}$$

Our results show that the equality (5) is perfect.

The analytical solution of the differential equation 2 or 6 under conditions (3) is:

$$P = P_0 \frac{K_1 + K_2}{P_0\left(\frac{K_1}{C_1} + \frac{K_2}{C_2}\right) + \left[K_1 + K_2 - P_0\left(\frac{K_1}{C_1} + \frac{K_2}{C_2}\right)\right] e^{-(K1+K2)t}} \tag{7}$$

We can write equation 7 for one of two stages in the following form:

$$\frac{1}{P} = \frac{1}{C_i} + \left(\frac{1}{P_0} - \frac{1}{C_i}\right) e^{-\mu_i t} \qquad i = 1, 2 \tag{8}$$

After taking in a logarithm we have:

$$-\ln\left(\frac{1}{P} - \frac{1}{C_i}\right) = -\ln\left(\frac{1}{P_0} - \frac{1}{C_i}\right) + \mu_i t \qquad i = 1, 2 \tag{9}$$

This is an equation of a straight line with an angular coefficient μ_i. Using values of P, determined by the experiment, we can construct a plot of $-\ln(1/P - 1/C_i)$ as a function of the time and determine the values of μ_i ($i = 1, 2$).

Results and Discussion

Comparative analysis of treatment with different salts

The percentages of mortality and body weight gain correspond to data presented in previous studies by Gabrashanska *et al.* (1993, 1999a,b) and Galvez-Morros *et al.* (1995) and are shown in table 1. The P-values have been found and a comparison between the displayed data suggests an effective and good balanced therapy for chickens with ascaridiasis.

Previous work has shown that basic salts are more effective compared with neutral salts (Gabrashanska *et al.*, 1993, 1999a; Galvez-Morros *et al.*, 1995). The resorbtion of basic salts by the host is lower compared with neutral salts and therefore their action on intestinal nematodes is prolonged, ensuring a higher antiparasitic effect. The number of worms of *A. galli* in basic salt treatment is significantly lower than that in neutral salt treatment in all experiments ($P_{23} < 0.01$) (table 1). The basic salts, at the same time, show a lower toxicity for the host, as shown by lower host mortality. The most expressed and statistically significant difference between the action of basic and neutral salts is seen in the case of pure copper salts with chickens infected on 14 day p.h. ($P_{23} < 0.05$), (table 1). In the case of pure zinc salts an enhanced effect of basic salts compared with neutral salts is observed for 30 days p.h. infected chickens. This may be due to the respective doses of Zn-basic salts being slightly more toxic to smaller chickens. With reference to the gain in host body weight, a statistical difference is established in the treatment of infected chickens between neutral and basic mixed salts for 14 days p.h. ($P_{23} < 0.1$). A significant reduction in host mortality and a gain in body weight are also evident in more chickens treated with basic salts by day 30 p.i. An increase in the mortality of chickens treated with neutral copper and zinc salts from 30 to 60 day p.i. indicates the high toxicity of these salts. The toxicity of mixed Cu–Zn neutral salts is higher and at 30 day p.i. host mortality is significant and greater in comparison with pure salts. Thus, basic salts appear to achieve better therapeutic results, especially, in decreasing worm burden and host mortality.

A comparative analysis of treatment with different basic salts is presented in table 2, indicating P-values of chicken mortality, gain in body weight and parasite burden. In chickens infected on day 14 p.h. mortality in the case of treatment with pure copper salts at 60 days p.i. is four times lower in comparison with pure zinc salts (table 1) and six times lower in comparison with mixed Cu–Zn salts treatment (table 2: $P_{Cu,Zn} < 0.05$; $P_{Cu,Cu-Zn} < 0.01$). A higher gain in body weight is observed both in mixed and pure copper salt treatment, although the differences are not statistically significant, whereas differences in worm burden are small.

In chickens infected on day 30 p.h., differences in host mortality and gain in body weight between treatment with pure copper and zinc basic salts are not statistically

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Table 1. Percentage of host mortality and body weight gain and mean worm number in seven experiments with different treatments of chickens infected with *Ascaridia galli* at 14 and 30 days post-hatching.

Salts	Infected at	Number of chickens	Group N	Status and treatment	Mortality % 30	Mortality % 60	P day 60	Weight gain % 30	Weight gain % 60	P day 60	Worm number (mean + SE)	P day 60
Pure Cu	14	20	0	Healthy	10	10	$P_{01}<0.01$	96	175.6	$P_{01}<0.1$		
			1	Infected	25	50	$P_{12}<0.1$	49	95.2	$P_{12}<0.1$	18±2.5	$P_{12}>0.1$
			2	Neutral	15	25	$P_{13}<0.001$	90.6	147	$P_{13}<0.1$	18.8±3.9	$P_{13}<0.01$
			3	Basic	5	5	$P_{23}<0.05$	103	167	$P_{23}>0.1$	10±4.7	$P_{23}<0.01$
	30	30	0	Healthy	6.7	6.7	$P_{01}<0.001$	91	176	$P_{01}<0.05$		
			1	Infected	37	47	$P_{12}>0.1$	38	70	$P_{12}>0.1$	28.7±5.2	$P_{12}<0.01$
			2	Neutral	27	33	$P_{13}<0.01$	43	133.7	$P_{13}<0.1$	21±4.8	$P_{13}<0.001$
			3	Basic	16.6	16.6	$P_{23}<0.1$	67	126.6	$P_{23}>0.1$	9±2.9	$P_{23}<0.001$
Pure Zn	14	30	0	Healthy	6.7	6.7	$P_{01}<0.001$	91	176	$P_{01}<0.05$		
			1	Infected	37	47	$P_{12}>0.1$	38.5	70	$P_{12}>0.1$	18±2.8	$P_{12}>0.1$
			2	Neutral	17	30	$P_{13}>0.02$	46.2	93.6	$P_{13}<0.1$	19.6±3.1	$P_{13}<0.01$
			3	Basic	17	20	$P_{23}>0.1$	71	135	$P_{23}>0.1$	12.4±1.8	$P_{23}<0.001$
	30	18	0	Healthy	11	11	$P_{01}<0.05$	13	20.5	$P_{01}>0.1$		
			1	Infected	28	39	$P_{12}>0.1$	7	14.8	$P_{12}>0.1$	29.4±6.2	$P_{12}>0.1$
			2	Neutral	17	28	$P_{13}<0.05$	8.5	18.2	$P_{13}>0.1$	22.3±3.9	$P_{13}<0.001$
			3	Basic	11.1	11.1	$P_{23}<0.1$	10.5	18.5	$P_{23}>0.1$	17.4±5.1	$P_{23}<0.01$
Mixe Cu–Zn	14	30	0	Healthy	6.7	13	$P_{01}<0.001$	95	173	$P_{01}<0.05$		
			1	Infected	37	53	$P_{12}<0.1$	29	64.5	$P_{12}>0.1$	32.9±2.2	$P_{12}<0.01$
			2	Neutral	37	40	$P_{13}>0.05$	37	134.8	$P_{13}<0.1$	25±4.1	$P_{13}<0.001$
			3	Basic	30	30	$P_{23}>0.1$	83	173.6	$P_{23}<0.1$	10.4±0.9	$P_{23}<0.001$
	30	30	0	Healthy	6.7	13	$P_{01}<0.001$	63	115	$P_{01}>0.05$		
			1	Infected	43	53	$P_{12}>0.1$	19	47.5	$P_{12}>0.1$	35±1.8	$P_{12}<0.001$
			2	Neutral	43	40	$P_{13}>0.1$	23	74.8	$P_{13}<0.1$	18.8±1.9	$P_{13}<0.001$
			3	Basic	40	43.3	$P_{23}>0.1$	31	86.7	$P_{23}>0.1$	15.4±0.6	$P_{23}<0.01$
Mn	14	30	0	Healthy	3.3	6.7	$P_{02}>0.1$	401.7	715.8	$P_{02}>0.1$		
			1	Healthy, inorg.	0	0	$P_{12}>0.1$	433.3	757.03	$P_{12}>0.1$		
			2	Healthy, org.	0	3.3	$P_{03}<0.01$	444.58	809.5	$P_{03}<0.01$		
			3	Infected	36.7	40	$P_{34}>0.1$	369.3	538.8	$P_{34}>0.02$	45.72±2.18	$P_{34}<0.01$
			4	Inf., inorg.	30	36.7	$P_{35}<0.1$	371.6	701.2	$P_{35}<0.01$	69.45±3.22	$P_{35}<0.001$
			5	Inf., org.	26.7	26.7	$P_{45}>0.1$	384.2	723.1	$P_{45}>0.1$	80.5±1.97	$P_{45}<0.01$

'30' and '60' are: days post-infection in the experiments with Cu and Zn salts; days post-hatching in the experiment with Mn.

significant: $P_{Cu,Zn} > 0.1$ (table 2). Therapy with pure copper salts compared with other salts shows the best result as a reduction in worm burdens of *A. galli* is visible (tables 1, 2).

This result is not unexpected, as besides having antiparasitic activity (Stepanjan & Sakyljan, 1981; Gabrashanska *et al.*, 1993), copper in biotic doses increases host immunity (Babenko & Reshetkina, 1971). The concept of using mixed salts, on the one hand, was to fulfil a more compact and complete therapy. Gabrashanska *et al.* (1999a) showed that chicken mortality increased with mixed Cu–Zn basic salt treatment compared with pure basic Cu salt, suggesting a higher toxicity of the mixed basic salt. However, the results relating to gain in body weight and worm burden levels were similar in both types of treatment.

The reason why the pure copper salt acts on infected chickens with more efficiency on day 14 compared with day 30 p.h. might be explained by host age, as younger animals, apart from having a greater need for copper, are also able to utilize copper more effectively (Babenko & Reshetkina, 1971).

The gain in body weight in chickens treated with manganese compounds is several times higher than that

Table 2. A comparison of P values, presented at day 60 post infection, for chicken mortality (%), body weight gain (%) and number of *Ascaridia galli* in chickens infected on days 14 and 30 post-hatching and treated with copper, zinc, a copper–zinc mixture and manganese.

Days post-hatching	P day 60	Host mortality	Gain in host body weight	Number of *Ascaridia galli*
14	$P_{Cu,\ Zn}$	<0.05	>0.1	<0.05
	$P_{Cu,\ Cu–Zn}$	<0.01	>0.1	>0.1
	$P_{Zn,\ Cu–Zn}$	>0.1	>0.1	<0.1
	$P_{Cu,Mn\ inorg}$	<0.01	<0.001	<0.001
	$P_{Cu,\ Mn\ org}$	<0.05	<0.001	<0.001
30	$P_{Cu,\ Zn}$	>0.1	>0.1	<0.001
	$P_{Cu,\ Cu–Zn}$	<0.02	<0.1	<0.001
	$P_{Zn,Cu–Zn}$	<0.01	<0.1	<0.1

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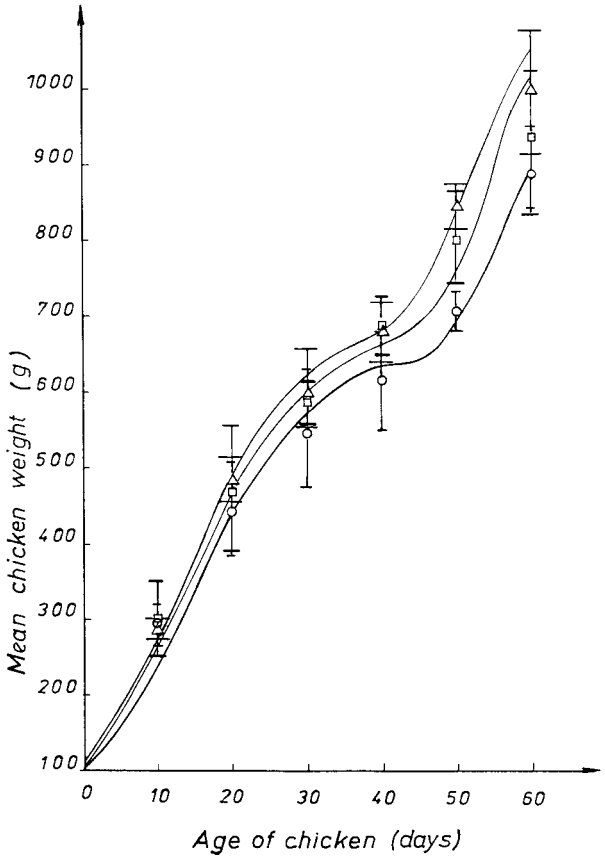

Fig. 1. Time course of the mean body weight of healthy chickens, untreated or treated with manganese compounds up to 60 days post-hatching. ○, Untreated; □, treated with $MnSO_4.H_2O$; △, treated with $2Gly.MnCl_2.2H_2O$.

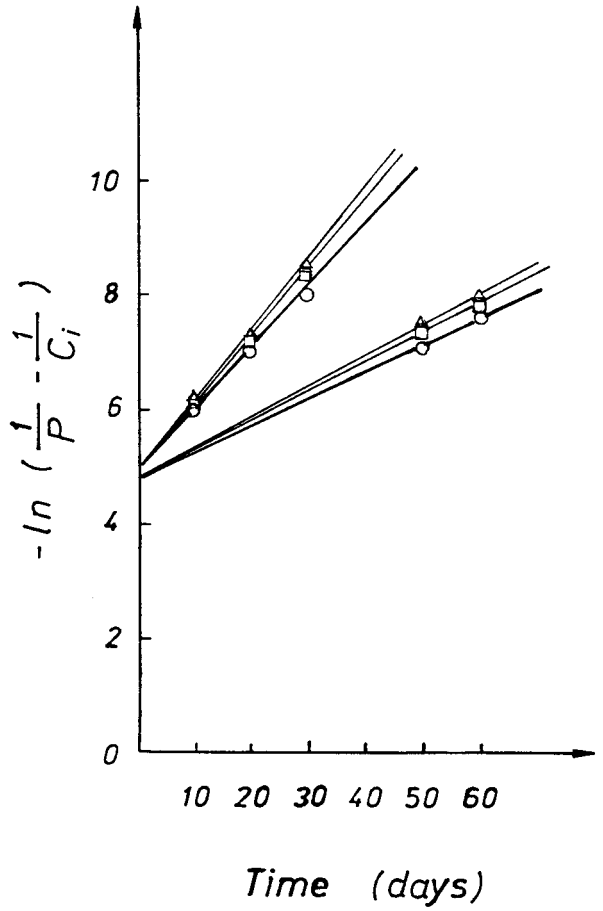

Fig. 2. Determination of phenomenological constants μ_1 and μ_2 (relative growth rates) on the basis of equation 9 using experimental measures of the chicken body weight. ○, Control group – healthy untreated chickens; □, group 1 – healthy, treated with $MnSO_4.H_2O$; △, group 2 – healthy, treated with $2Gly.MnCl_2.2H_2O$.

in chickens treated with copper and zinc salts (tables 1, 2). In chickens infected on day 14 p.h., the gain in body weight in organic Mn salt treatment is 4.3 times higher than in the case of pure basic Cu salt. Manganese is known to increase bird growth and correct skeleton deformation caused by ascaridiasis (Berenschtein, 1968, Watson *et al.*, 1970). In addition, the availability of manganese from Mn^{2+}/protein is higher compared with inorganic Mn salts (Black *et al.*, 1984; Smith *et al.*, 1995; Gabrashanska *et al.*, 1999b) and in chickens infected with *A. galli* worm burdens increased with manganese salt treatment and worm numbers and growth were stimulated by an excess of manganese and glycine. (Gabrashanska *et al.*, 1999b). However neither host mortality nor body weight were affected.

In conclusion, we recommend the following treatment for birds with ascaridiasis: five daily doses, followed by a 7-day interval, containing 8 mg Cu^{2+} in the form of pure basic salt $Cu_2(OH)_3Cl$ and 0.9 g Mn^{2+} kg^{-1} food in the form of organic manganese compound $2Gly.MnCl_2.2H_2O$. The food should comprise conventional corn–soybean meal diet with adequate amounts of vitamins and minerals, without copper supplementation, with Zn suplementation, and with 157 mg Mn^{2+} kg^{-1} food, formulated to meet the nutrient requirements of growing chickens (US National Research Council, 1994). This type of treatment will be close to optimal, as it ensures good antiparasitic activity, a stable immune status, low host mortality and a high gain in body weight. At the same time, deformation of the skeleton and unfavourable changes in host reproduction are unlikely to occur.

Growth kinetics of uninfected and untreated chickens

The mathematical model proposed in the present study has been applied to three groups of chickens treated with manganese compounds, namely group 0 (control); group 1 (chickens uninfected, treated with $MnSO_4.H_2O$); group 2 (chickens uninfected, treated with $2Gly.MnCl_2.2H_2O$). The analytical solution (7) of the differential equation (2) is in good agreement with experimental data for mean chicken weight P [g] (fig. 1).

Using the equation 9 and on the basis of experimental data, the resulting plots are shown in fig. 2. The constants

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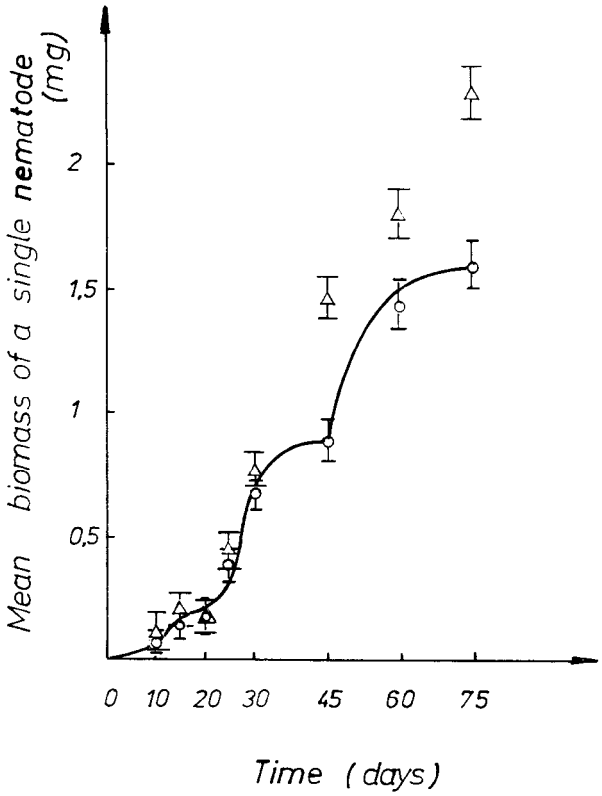

Fig. 3. Time course of the average biomass growth of a single *Ascaridia galli* (model solution given for male nematodes only). ○, Males; △, females.

μ_1 and μ_2 are equal to the angular coefficients of the straight lines. We obtain respectively:

For group 0: $\mu_1 = 0.111$, $\mu_2 = 0.0466$
For group 1: $\mu_1 = 0.119$, $\mu_2 = 0.05$
For group 2: $\mu_1 = 0.123$, $\mu_2 = 0.053$

μ_1 and μ_2 are the relative rates of mean chicken weight for two development stages.

The moment T, which indicates the transfer from the first to the second stage, has been determined from the equation:

$$\frac{\mu_1}{P_0\frac{\mu_1}{C_1}+\left(\mu_1 - P_0\frac{\mu_1}{C_1}\right)e^{-\mu_1 t}} = \frac{\mu_2}{P_0\frac{\mu_2}{C_2}+\left(\mu_2 - P_0\frac{\mu_2}{C_2}\right)e^{-\mu_2 t}} \quad (10)$$

The transfer between two development stages does not take place simultaneously for all chickens so that the moment T is related to the most likely day this transfer occurred. On the basis of equation 10 we obtain respectively:

For group 0: $T = 46.26 \approx 46$ day p.h.
For group 1: $T = 43.34 \approx 43$ day p.h.
For group 2: $T = 42.3 \approx 42$ day p.h.

This result is in agreement with experimental data (fig. 1) and represents an acceleration of the growth of healthy chickens treated with manganese compounds. This acceleration is greater in the case of treatment with 2Gly.$MnCl_2$.$2H_2O$) if only for one day.

The theoretical curves in fig. 1 have been calculated on the basis of the values of growth rate constants μ_1 and μ_2, under the initial conditions for the three chickens groups where $P_0 = 109\,g$ and under values of C_i $(i = 1, 2)$ determined by the program 'Minuit', where, for the control group, $C_1 = 675\,g$, $C_2 = 1700\,g$ and for groups 1 and 2, $C_1 = 700\,g$, $C_2 = 1800\,g$.

In fig. 3 are presented a theoretical curve and experimental results obtained in the study by Gabrashanska & Teodorova (1998) on the development and growth kinetics of *A. galli* in chickens although the theoretical result, a solution of respective logistic equation, is only in close agreement with the growth of male worms.

The fact that similar mechanisms of biomass growth are observed in substantially different organisms is an expression, on a phenomenological level, of the universality of genetic processes in eukaryotes. On the other hand, such models could provide more precise quantitative studies of biological phenomena with particular reference to organism growth. The kinetic parameters (in the present case, relative growth rates represented by μ_i) might be considered as characteristics phenomenological parameters of a range of species and their values could be determined more precisely.

References

Ackert, G. (1942) Natural resistance to helminthic infection. *Journal of Parasitology* **28**, 1–14.

Babenko, G. & Reshetkina, L. (1971) *Application of the microelements in medicine*. Kiev, Zdorovja Publishing House (in Russian).

Balayan, D.E. (1982) On the effect of helminthoses on the content of microelements (copper, molybdenum, manganese, iron, zinc) in tissues and organs of sheep. *Zoological Papers, XVIII* **46**, 245–257 (in Russian).

Berenschtein, F. (1968) *Microelements, biological role and their importance for stock-breeding*. Kiev, Urogaj.

Bergter, F. (1972) *Wachstum von Microorganismen*. Jena.

Black, J., Ammerman, C., Henry, P. & Miles, R. (1984) Biological availability of manganese sources and effect of high dietary manganese on tissue mineral composition of broiler-type chicks. *Poultry Science* **63**, 1999–2006.

Davis, G. & Mertz, W. (1987) Copper. pp. 301–364 *in* Mertz, W. (*Ed.*) *Trace elements in human and animal nutrition Vol. 1*. New York, Academic Press.

Davtjan, E.A. (1982) On microelements like factors changing host-parasite relationships during helminthiases and on the possibility for their application for raising of animal production. *Biological Journal of Armenia* **30**(4), 2–5 (in Russian).

Duncan, D.B. (1955) Multiple range and multiple F tests. *Biometrics* **11**, 1–42.

Gabrashanska, M. & Teodorova, S. (1998) Development and growth kinetics of *Ascaridia galli* in chickens. *Experimental Pathology and Parasitology* **1**, 8–13.

Gabrashanska, M., Daskalova, A. & Ossikowski, E.

https://doi.org/10.1079/JOH200189 Published online by Cambridge University Press

(1986) Veränderungen im Status der Spurenelemente von Küken bei Experimenteller Infection mit *Ascaridia galli*. *Monatschefte für Veterinarmedizin* **41**, 446–450.

Gabrashanska, M., Daskalova, A. & Ossikowski, E. (1987) Comparative investigations on the microelement status of *Ascaridia galli* (Schrank, 1788; Freeborn, 1923) and its host (*Gallus gallus*). *Helminthologia* **24**, 209–214.

Gabrashanska, M., Galvez-Morros, M.M. & Garcia-Martinez, O. (1993) Application of small doses of copper salts (basic and neutral) to *Ascaridia galli*-infected chicks. *Journal of Helminthology* **67**, 287–290.

Gabrashanska, M., Teodorova, S., Galvez-Morros, M. & Garcia-Martinez, O. (1999a) A kinetic model for *Ascaridia galli* populations in chickens treated with mixed salts of copper and zinc. *Journal of Helminthology* **73**, 45–50.

Gabrashanska, M., Tepavitcharova, S., Balarew, C., Galvez-Morros, M.M. & Arambarri, P. (1999b) The effect of excess dietary manganese on uninfected and *Ascaridia galli* infected chicks. *Journal of Helminthology* **73**, 313–316.

Galvez-Morros, M., Gabrashanska, M., Lopez-Galvez, D. & Garcia-Martinez, O. (1995) Comparison of the effects of basic and neutral zinc salts on chicks infected with *Ascaridia galli*. *Veterinary Parasitology* **56**, 199–205.

Kennedy, C.R. (1975) *Ecological animal parasitology*. Oxford, Blackwell Scientific Publications.

Smith, M., Sherman, Y., Miller, L., Robbins, K. & Halley, J. (1995) Relative biological availability of manganese from manganese proteinate, manganese sulphate and manganese monoxide in broilers reared in elevated temperatures. *Poultry Science* **74**, 702–707.

Southern, D. & Baker, E. (1978) Zinc toxicity, zinc deficiency and Zn–Cu relationship in *Eimeria acervulina* infected chicks. *Journal of Nutrition* **112**, 2353–2359.

Stepanjan, P.G. & Sakyljan, A.C. (1981) The effect of a colamine-phosphate and copper sulphate on the implantibility of ascaridiasis in chicks. *Biological Journal of Armenia* **34**, 3–10 (in Russian).

Svirezhev, J.M. (1981) *Mathematical models in the ecology and genetics*. Moskva, Naouka Publishing House (in Russian).

US National Research Council (1984) *Nutrient requirements of poultry*. 8th rev. edn, Washington, DC, National Academy Press.

US National Research Council (1994) *Nutrient requirements of poultry*. 9th rev. edn, Washington, DC, National Academy Press.

Vassilev, I., Ossikovski, E., Bozhkov, S., Kambourov, P., Bankov, I. & Roupova, L. (1973) On the pathogenesis of ascaridiosis in fowl. *Bulletin of the Central Helminthological Laboratory (Sofia)* **16**, 43–58.

Watson, H.T., Ammerman, C. & Miller, M.S.Harms, R.H. (1970) Biological assay of inorganic manganese for chicks. *Poultry Sciences* **49**, 1548–1554.

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