STATISTICAL MODELS IN GROWTH STUDIES OF RABBIT

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THESIS

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Department of Agricultural Statistics

COLLEGE OF HORTICULTURE

Vellanikkara Thrissur

1997

DECLARATION

I hereby declare that this thesis entitled ***Statistical models in growth studies of rabbit*** *is a bonafide record of research work done by me during the course of research work and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship fellowship or other similar title of any other University or Society*

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To
My parents

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Introduction

INTRODUCTION

Of late rabbit is a subject of tremendous interest with regard to their potential as meat producing animal The local meat production has failed to satisfy the increased consumption needs If the needs for meat consumption is to be met, much of the increase in production will have to come from short cycle animals, especially those animals like rabbits being kept by the small scale farmers Further, rabbits are characterized by small body size and they also have the economic advantage of thriving on feed stuffs rich in roughage Hence rabbit seems to have a good potential as a meat producing animal especially when its prolificacy and growth rate are considered

The emerging trends in agriculture the changes in land use pattern, changing trends of cultivation and increase in human population compel identification, selective breeding and propagation of animal species which are prolific and that can grow faster converting feeds not utilised by men Small livestock like rabbits have a number of characteristics that are advantageous to small holder, subsistance type integrated farming and gardening food production systems in developing countries. In this respect rabbit rearing is very much advantageous to a small holder in comparison to other animal species As rabbit meat is a delicacy in most of the developed and developing countries, it is having a huge demand In order to make rabbit rearing more advantageous and economical growth rates of various species of rabbits are to be critically studied. As the meat production mainly depends upon the growth rate of the different species it is imperative to have a critical study of its growth rate over a period of time under the different climatical conditions Suitable relationship suggested under the study will be helpful to the rabbit farmers for making suitable selection of breed and the economically viable period for making maximum profit

Unfortunately the studies in this direction are rather scanty Hence the present investigation was undertaken with the objectives to find suitable relationship between age and body weight of different breeds of rabbit viz Newzealand White, Soviet Chinchilla and Grey Giant and to study the impact of climatic elements (temperature and humidity) on body weight

Review of Literature

REVIEW OF LITERATURE

Growth curves reflect the life time inter relationship between an individuals inherent impulse to grow and mature in all body parts and environment in which these impulses are expressed. Knowledge of growth curves is important to all biologists regardless of specialisation who are concerned with the effects of their research and recommendations on life time production efficiency Development of the theory and techniques for fitting growth curves may be traced both through time and scientific disciplines In particular the theory and methodology of fitting growth curves owes much to the mathematicians demographers and economists A review of growth curve analyses in the rabbits (*Oryctolagus Cuniculus*) and some other species are presented here

2 1 Growth studies (general)

In 1825 Gompertz (See Winsor 1932) developed a model

$W_t = W_\alpha \, Exp\{ [ln(W_\alpha) \; ln(W_t)]Exp[\; k(t \; t)]\}$ which is obtained by integrating the differential equation in terms of natural logarithm with respect to 't

$$dW_t/dt = kW_t[ln(W_\alpha)\text{-}W_t]$$

where W_α = maximum weight

W_t = weight at time 't

k = proportionality of growth rate constant.

Integrating Bertalanffy's (1949) differential equation,

$dW/dt = aW^m \; bW$ a b and m are constants yielded the following growth curves

$W = a/b \; (a/b \; W_0^{1 \; m})Exp(\; b(1 \; m)t)^{1/1 \; m}$ where W_0 is weight at time t=r

When m=0, $W=a/b\text{-}(a/b\text{-}W_0)Exp(\; bt)$ which is modified exponential

When m=2 $W=[a/b \; (a/b \; W_0)Exp(\; bt)]^{1}$ which is logistic curve

When m=1 the original differential equation gives the exponential curve and is given by $W=W_0 Exp[(a b)t]$

Under certain important assumptions on constants and letting m >1, this differential equation tends to Gompertz equation of the form

$W > A\ Exp[B\ Exp(kt)]$ where $A >(a/b)^{1\ m}$, $B=\ln(W_0/A)$, $k >b(m\ 1)$

Vehulst (1838)(See Allee *et al*, 1949) developed an equation to describe population growth and termed the function for this S shaped curve, the logistic function The equation for rate of gain from which the logistic function was derived is $dW/dx = kW_x(W_\alpha\ \ W_x)/W_\alpha$ which indicates that the instantaneous rate of gain is a function of growth already made and potential for growth

Rearranging the above equation and then integrating using partial fraction between t_0 and t with respect to x, we obtain

$W_t = W_\alpha(1+(W_\alpha/W_t)\ 1))Exp(\ k(t\ t_0))^{1}$ This equation relates weight at a given time to a function of initial and final weights, growth rate constant and time

Richards (1959) used an extended form of Von Bertalanffy's growth function

$W=(\eta/k\ (\eta/k\ W_0^{1\ m})Exp(\ (1\ m)kt))^{1/(1\ m)}$ (2 1 1)

(which is sygmoid) to plant data for supplying an empirical fit.

Here W_0 = weight at t=0 η (eta) and k are proportionality constants of anabolism and catabolism m = slope of Bertalanffy's relation

Equation (2 1 1) can be written as

$$W^{1\ m} = A^{1\ m}\ \beta Exp(\ kt) \qquad (2\ 1\ 2)$$

where $A^{1\ m} =\eta/k$ $\beta=(\eta/k)\ W_0^{1\ m}$ $k = (1\ m)k$ are constants

Therefore $W^{1 m} = A^{1 m}(1 bExp(kt))$ when $m<1$ (2 1 3)

$W^{1 m} = A^{1 m}(1+bExp(kt))$ (2 1 4)

where $b\pm\beta A^{m-1}$

When m=0 equation (2 1 4) reduces to modified exponential form

$W = A(1 bExp(kt))$

When m=1 equal (2 1 2) is insoluble

When m lies between 0 and 1 the curves are transitional in form between the modified exponential and Gompertz and when m lies between 1 and 2 the curve lies between Gompetz and logistic

It was derived that as m >1 equation represents the Gompertz equation

$W = A Exp[b Exp (kt)]$ where W = size at time t' A = ultimate limiting value

k = constant of catabolism

Nelder (1961) developed a logistic function of the form

$W_t = W_\alpha[1+((W_\alpha/W_t)^{1/\theta} 1)Exp(k(t t)/\theta]^{-\theta}$ which is a generalization of logistic function given in differential equation of the form

$dW_x/dx = kW_x(1 (W_x/W_\alpha))$ suggested by Vehulst (1838) (See Allee *et al*, 1949)

Here W_α = maximum weight and W_x = weight of animal at time x'

Nelder (1962) (on reparameterization of Nelder 1961) developed a logistic model of the type $W_t = W[1+((W_\alpha/W_t)^u 1)Exp(uk(t t))^{1/u}$ which is obtained by integrating the differential equation $dW_x/dx = kW_x(1 (W_x/W)^u)$ between t' and t with reference to x' and letting $u=1/\theta$

Bhattacharya (1966) generalized the growth function suggested by Von Bertalanffy as $Y = (\alpha+\beta\gamma^{t})^{\delta}$ where α β γ and δ are parameters
The equation reduces to modified exponential when δ=1, logistic equation when δ= 1, Gompertz equation when δ >∞

Laird *et al* (1968) used a growth equation of the Gompertz type $W= W_0Exp[A_0/\alpha(1\ Exp(\ \alpha t))]$ $A= A_0Exp(\ \alpha t)$ where W = weight at time t', W_0 = initial weight at the start of the period of observation A_0 and A are specific growth rates at the starting time and at time t respectively α is the rate of exponential decay of A_0 for representing the growth of individual parts of organism and of the whole organism

Pruitt and Turner (1978) have proved that general theory of growth is useful in numerical analysis Of many and diverse biological and biochemical processes The range of applicabiliy of the theory is illustrated by the fact that it yields

(1) the logistic curve $[1+Exp(\ \beta(t\ \tau))]^{1}$ with point of inflexion 1/2

(2) the Gompertz $Exp[\ Exp(\ \beta\ (t-\tau))]$ with point of inflexion 1/e

(3) Bertalanffy Richards function $[1+Exp(\ n\beta(t-\tau))]^{1/n}$ with point of inflexion $(1+n)^{1/n}$

Here τ is the constant of integration and is growth curve parameter

2.2 Growth studies in rabbits

The results obtained by Biggs (1959) from plotting weights of 61 English spotted rabbits show that the growth curve is the typical sygmoid curve He also gave the body weight at the age of 150 days as about 2400 g for male and 2200 g for females

The growth performance of 96 male and female light coloured Large Silver rabbits up to one year of age was studied by Niehaus (1963) Average daily gain was 22 26 and 33 g during the first second and third months respectively, after which it declined. He concluded that it is uneconomic to fatten rabbits beyond the third or atmost fourth month of age

Gogeliya *et al*(1982) reported that the body weight at 120 days of age averaged 1080 g for Soviet Chinchilla and Greygiant rabbits and there was no significant breed difference

Damodar and Jatkar (1985) reported that the ten week body weight for Newzealand White and Greygiant rabbits was 1880 and 2170 g respectively They also noted that age of maturity for Newzealand White rabbits was 165 days

In the study conducted by Zimmermann *et al* (1988) they found that Newzealand White rabbit s body weight at eight and twelve weeks of age were 1766±368 g and 2770±316 g respectively for males and 1702±285 and 2718±324 g for females

Oetting *et al* (1989) studied the growth rates and body measurements in Newzealand White Jappanese White and their crossbred rabbits and found that growth was faster and mature body weight of female greater in crossbred rabbits than in Newzealand White or Jappanese White rabbits

Vicente *et al* (1989) studied prediction equations in rabbits growth Equations obtained from a sample of 100 female rabbits of a synthetic meat line were used to predict body conformation and carcass composition of a population of Newzealand White and Californian rabbits The equations and correlation between the various body conformation and carcass traits were studied. The coefficient of determination for the various traits ranged from 0 72 to 0 99 and the correlation between traits from 0 73 to 0 99

In an experiment conducted by Kumar *et al* (1991) 32 Newzealand White and 50 local non descript rabbits were reared in cages on a litter floor from four week of age The Newzealand White were heavier at the start of the experiment and had a higher average weekly body weight gain from four to ten weeks age than the non descript rabbits

Gomez and Blasco (1992) fitted logistic, Gompertz and Richards growth curves to the weekly body weights of two synthetic lines of rabbits, cross bred rabbits and Californian rabbits and found that Gompertz curve was the most appropriate curve to describe the growth pattern

Radhakrishnan (1992) observed that during the weeks 4, 6, 8, 10 and 12 the body weights of rabbits varied significantly between breeds Newzealand White rabbits had the lowest weight through out the period of study in all the respective weeks while Soviet Chinchilla had maximum weight from among the breds throughout the period of study He also noticed that among the three breeds there was no significant difference between sex

The body weights of hybrid rabbits of age 70 days were 2 2, 2 4, 2 6 kg in the experiment conducted by Roiran *et al* (1992) The average carcass yield was 55 6, 55 6 and 57 2 per cent respectively vs 55 8,56 9 and 57 4 for rabbits slaughtered at 77 days at the same body weights The differences between carcass yield of rabbits slaughtered at 2 kg and those slaughtered at 2 4 and 2 6 kg were significantly different.

Wang and Jiang (1992) fitted Gompertz model to body weight data on German Angora Chinese Angora rabbits and crosses of these two strains Good fits were obtained for pure breds and cross breds They also pointed out that the maximum growth was at two to three months of age at inflexion was at 77 to 93 days

Yamani *et al* (1992) observed that the inflexion point of sygmoid growth curve of the rabbits tended to be at 8 to 10 weeks

Yang and Miao (1992) took data for body weights of broiler rabbits and exponential growth curve was fitted. Its goodness of fit was 0 9342 compared with 0 9796 and 0 9554 that for the logistic and Gomperz model respectively

2.3 Growth studies in some other species

Laird (1965) fitted the Gompertz equation to growth curves of several varieties of domestic chicken, turkey, goose, duck and quail

Growth curves were constructed by Susaki (1966) from data on the body weight of three broiler breeds and three crosses of ducks up to 10 weeks of age Curves of the type $Y=ax^b$ (exponential) $Y=a+bx+cx^2$ (quadratic) and $Y=a+bx+c\log(x)$ all gave a satisfactory fit to the data

Buffington *et al* (1973) used different statistical models for the growth data of male and female white turkeys He found that the Gompertz equation provided an excellent fit to the data

Indirabai *et al* (1985) reported that the growth curves of the form $Y=a+bx$ (linear) and $Y=ae^{bx}$ (exponential) were suitable for predicting the pattern of growth in broiler chicken

John Thomas (1991) fitted various statistical models and found that Gompertz curve was the best one for ascertaining growth in quails over twelve weeks having higher R^2 and lower standard error of estimate

Bardoloi *et al* (1992) fitted linear and exponential growth curves to body weight data for 1050 Landrace pigs collected from birth to 32 week of age The linear equation fitted to the data was better than the exponential curve

Preez *et al* (1992) fitted the Gompertz model to body weight data of ostriches raised under farm conditions He also estimated mature body weight from the Gomperz model

Ahunu *et al* (1994) fitted Bertalanffy Gompertz logistic and Richards models to the monthly body weights of 90 cows They have got high value of R^2 for Richards equation (96 22%)

Materials and Methods

MATERIALS AND METHODS

The study was initiated using three different breeds of rabbit (*Oryctolagus Cuniculus*) The breeds used were Newzealand White Soviet Chinchilla and Greygiant The experiment consists of three parts Each part is of duration nearly four months, as the broiler rabbit attains the marketable weight within a period around three months

First time period October November December and January

Second time period February March April and May

Third time period June July August and September

In the first time period twenty numbers of one day old rabbits each of three breeds were procured from the Kerala Agricultural University Rabbit Research Station, Mannuthy and kept under standard diet and uniform feed for a period of four months

In the same manner twenty numbers of one day old rabbits each of the three breeds were kept under normal diet for the second and third time periods After few weeks the rabbits were divided in to male and females and moved to individual cages

Under each time period the body weight of each rabbit was recorded at weekly intervals until the rabbits attained an age of fifteen weeks Body length and body girth were also noted for each week The daily temperature and humidity were recorded during these periods

3 1 Fitting of growth curves

The body weight data so gathered were used for fitting appropriate functions of growth The following functions were considered

(i)	Linear	$W_t = a + bt$	(3 1 1)
(ii)	Quadratic	$W_t = a+b_1t+b_2t^2$	(3 1 2)
(iii)	Exponential	$W_t = a\ Exp(bt)$	(3 1 3)
(iv)	Von Bertalanffy	$W_t = a[1\ b\ Exp(kt)]^3$	(3 1 4)
(v)	Modified exponential	$W_t = k+ab^t$	(3 1 5)
(vi)	Logistic	$W_t = a[1+b\ Exp(\ kt)]^{1}$	(3 1 6)
(vii)	Gompertz	$W_t = a\ exp[\ b\ Exp(\ kt)]$	(3 1 7)

where a b b_1 b_2 and k are constants and W_t is the body weight at time t'
The parameters of the equations (3 1 1) to (3 1 4) were estimated using the method of least squares and the parameters of equations (3 1 5) to (3 1 7) were estimated by the method of partial sums (Croxton and Cowden 1964)

3 1 1 Linear

$$W_t = a + bt$$

The parameters a and b were estimated by the method of least squares

The normal equations are $\Sigma W_t = Na + b\Sigma t$

$$\Sigma tW_t = a\Sigma t + b\Sigma t^2$$

Solutions of the above normal equations are

$$a = (\ \Sigma t^2\Sigma W_t \quad \Sigma t\Sigma tW_t)/(\ N\Sigma t^2 \quad (\Sigma t)^2)$$

$$b = (N\Sigma tW_t \quad \Sigma t\Sigma W_t)/(\ N\Sigma t^2 \quad (\Sigma t)^2)$$

N is the total number of observations

3 1 2 Quadratic

$$W_t = a+b_1t+b_2t^2$$

The estimates of the parameters are obtained by solving the normal equations

$$\Sigma W_t = Na+b_1\Sigma t+b_2\Sigma t^2$$

$$\Sigma tW_t = a\Sigma t+b_1\Sigma t^2+b_2\Sigma t^3$$

$$\Sigma t^2W_t = a\Sigma t^2+b_1\Sigma t^3+b_2\Sigma t^4$$

and is given by $a = D_1/D$ $b_1 = D_2/D$ $b_2 = D_3/D$

$$D_1 = \begin{vmatrix} \Sigma W_t & \Sigma t & \Sigma t^2 \\ \Sigma tW_t & \Sigma t^2 & \Sigma t^3 \\ \Sigma t^2W_t & \Sigma t^3 & \Sigma t^4 \end{vmatrix}$$

$$D_2 = \begin{vmatrix} N & \Sigma W_t & \Sigma t^2 \\ \Sigma t & \Sigma tW_t & \Sigma t^3 \\ \Sigma t^2 & \Sigma t^2W_t & \Sigma t^4 \end{vmatrix}$$

$$D_3 = \begin{vmatrix} N & \Sigma t & \Sigma W_t \\ \Sigma t & \Sigma t^2 & \Sigma tW_t \\ \Sigma t^2 & \Sigma t^3 & \Sigma t^2W \end{vmatrix}$$

$$D = \begin{vmatrix} N & \Sigma t & \Sigma t^2 \\ \Sigma t & \Sigma t^2 & \Sigma t^3 \\ \Sigma t^2 & \Sigma t^3 & \Sigma t^4 \end{vmatrix}$$

N is the total number of observations

3 1 3 Exponential

$$W_t = a\ Exp(bt)$$

It can be converted in to linear by taking natural logarithm on both sides

$$\ln(W_t) = \ln(a) + bt$$

$$Z_t = A + bt \quad \text{where } Z_t = \ln(W_t) \text{ and } A = \ln(a)$$

$$\text{Then} \quad b = (N\Sigma tZ_t \quad \Sigma t\Sigma Z_t)/(N\Sigma t^2 \quad (\Sigma t)^2)$$

$$a = \text{Exp}(A) \qquad \text{where} \quad A = (\Sigma t^2\Sigma Z_t \quad \Sigma t\Sigma tZ_t)/(N\Sigma t^2 \quad (\Sigma t)^2)$$

N is the total number of observations

3 1 4 Von Bertalanffy

$W_t = a[1 \; b \, \text{Exp}(kt)]^3$ where a is mature body weight which is known, b and k are constants

$$(W_t/a)^{1/3} = 1 \; b \, \text{Exp}(kt)$$

$$b \, \text{Exp}(kt) = 1 \quad (W_t/a)^{1/3}$$

On taking natural logarithm on both sides

$$\ln(b) + kt = \ln[1 \; (W_t/a)^{1/3}]$$

$$B + kt = Z_t$$

The estimates of the parameters are

$$k = (N\Sigma tZ_t \quad \Sigma t\Sigma Z_t)/(N\Sigma t^2 \quad (\Sigma t)^2)$$

$$b = \exp(B) \qquad \text{where} \quad B = (\Sigma t^2\Sigma Z_t \quad \Sigma t\Sigma tZ_t)/(N\Sigma t^2 \quad (\Sigma t)^2)$$

3 1 5 Modified exponential

$$W_t = k + ab^t$$

The estimates of the parameters a 'b and k are

$$b = [(S_3 \; S_2)/(S_2 \; S_1)]^{1/n}$$

$$a = \frac{(S_2 \quad S_1)(b \; 1)}{(b^n \quad 1)^2}$$

$$k = 1/n[S_1 \quad ((b^n \; 1)/(b \; 1))a]$$

Here S_1 S_2 and S_3 are the sum of W_t values of three equal parts obtained from partial sums and n is the number observations in each part

3 1 6 Logistic

$W_t = a[1+b \; Exp(kt)]$ which can be written as

$Z_t = A + BC^t$ where $Z_t = 1/W_t$ $A = 1/a$ $B = b/a$ ans $C = Exp(k)$

The estimates are

$$C = [(S_3 \; S_2)/(S_2 \; S_1)]^{1/n}$$

$$B = \frac{(S_2 \; S_1)(C \; 1)}{(C^n \; 1)^2}$$

$$A = 1/n[S_1 \; ((C^n \; 1)/(C \; 1))B]$$

Then $k = \ln(1/C)$ $a = 1/A$ and $b = aB$

Here S_1 S_2 S_3 are the sum of Z_t values of three equal parts obtained from partial sums and n is the number of observations in each part

3 1 7 Gompertz

$W_t = a \; Exp[b \; Exp(kt)]$

which can be written as $Z_t = A + BC^t$

where $Z_t = \ln(W_t)$, $A = \ln(a)$ $B = b$ and $C = Exp(k)$

The estimates are given by

$$C = [(S_3 \; S_2)/(S_2 \; S_1)]^{1/n}$$

$$B = \frac{(S_2 \; S_1)(C \; 1)}{(C^n \; 1)^2}$$

$$A = 1/n[S_1 \; ((C^n \; 1)/(C \; 1))B]$$

then $a = Exp(A)$ $b = B$ and $k = \ln(1/C)$

where S_1 S_2 S_3 are the sum of Z_t values of three equal parts obtained from partial sums and n is the number of observation in each part of whorl maggot (WM) and number of dead heart (DH) at different time period Counts of number of silver shoot per plot indirectly indicated the severety of the attack of gall fly while those of dead heart indirectly showed the intensity of infestation of stem borer

The relevant details of the data collected on insect counts are as follows

Name of experiment	Trial on early stage pest control
Period of observation	1989 91
Design	Randomised Block Design (RBD)
Variety	Jaya
Season	Kharif
No of replication	4
No of treatments	8

Description of treatments

Treatment	Dose	Time and method of application
1 Furadon 3 G	2 kg/ai/hectare of nursery	Broadcast 5 days before pulling
2 Ekalux 5 G	do	do
3 Padan 4 G	do	do
4 Coroban 20 EC	1 5 kg/ai/hectare of nursery	Spray one day before pulling
5 Nuvacron 36 EC	do	do
6 Coroban 20 EC	0 05%	Whole seedling dip for 1 2 mts
7 Coroban 20 EC	0 02%	Seedling root dip for 12 hrs
8 Untreated control		

Secondary data on weed population were collected from the results of the post emergence herbicidal evaluation trial for *Pennisetum pedicellatum* The experiment was continued for a period of three years In each year data on number of surviving hills/m^2 were gathered from each plot at three time periods immediately after spraying the chemicals (or water) The three time periods were spraying at one month after sowing two months after sowing and three months after sowing Thus there were altogether 9 sets of data as detailed below

Serial no of data set	Year	Order of spray	Symbol
1	1987 88	Ist spray	$Y S_1$
2	1987 88	2nd spray	Y_1S_2
3	1987 88	3rd spray	Y_1S_3
4	1988 89	Ist spray	Y_2S_1
5	1988 89	2nd spray	Y_2S_2
6	1988 89	3rd spray	Y_2S_3
7	1989 90	Ist spray	Y_3S_1
8	1989 90	2nd spray	Y_3S_2
9	1989 90	3rd spray	Y_3S_3

The treatment details and other relevant information of the weed control trial are given below

Name of the experiment	Evaluation of post emergence herbicides for controlling *Pennisetum pedicellatum*
Period of observation	1987 90

Design RBD

No of treatments 13

No of replication 3

Descriptions of treatments

T_1 paraquat 0 4	T_7 glyphosate 0 7
T_2 paraquat 0 8	T_8 glyphosate 0 8
T_3 paraquat 1 2	T_9 glyphosate 1 2
T_4 Dalapon 2	T_{10} paraquat + Dimor 0 4+1
T_5 Dalapon 4	T_1 paraquat + Dimor 0 4+2
T_6 Dalapon 6	T_2 paraquat + Dimor 0 8+1
	T_{13} Control (water spray)

3 2 Methods of analysis of data

The various statistical methods used in the present study are outlined below

3 2 1 Empirical comparisons among different transformations

Comparisons among different transformations were made either based on a single criterion or several criteria simultaneously In the former approach the different transformations were evaluated for their relative efficiency m maintaining homoscedasticity or in restoring additivity Comparison of transformations were also effected in accordance with the Taylor s power law which invariably indicated the best transformation for a given set of data If the relation between variance and mean was parabolic inverse hyperbolic sine squareroot transformation could be considered to be a proper choice In the multiple criteria approach the prime objective was to choose a transformation that yielded to the maximum extent approximate normality additivity and homoscedasticity conditions of the linear model Box and Cox (1964) proposed a likelihood function approach for this purpose It would be possible to select the best power transformation as per the methods suggested by them

Draper and Hunter (1969) suggested a comprehensive graphical method for selecting the best transformation for a given set of data considering several single aspect criteria simultaneously The method is rather simple and useful to examine the adaptability of the likelihood approach

3 2 1 1 Comparison of transformations based on a single aspect

The two major violations of assumption of analysis of variance are (1) non additivity (2) heteroscedasticity Normality assumption usually goes hand in hand with homoscedasticity assumption

A comparison of the different transformations on the basis of the above criteria could be done in accordance with the relative degree of conformity of the transformed data under each scale to the underlying assumptions As far as stabilisation of variance was concerned the following two single aspect selection criteria were used to choose the best transformation (1) Bartlett s χ^2 test (2) Levene s F test of the residual ANOVA

The transformation that gave a minimum value for each of the above criteria was considered to be the most ideal

In the case of additivity assumption, Tukey s test of non additivity was used as the selection criterion The method consisted in calculating non additivity sum of squares with one degree of freedom and using the F statistic for the diagonostic test The best transformation should yield a minimum value for the non additive F Another possibility was to use treatment Vs error F statistic as a basis of comparison and choosing the transformation giving the highest value for F

3 2 1 1a Bartlett s chi square test

Let K independent samples of residuals $e_{ij} - Y_j$ Y (i − 1 2 k j = 1 2 n) be selected the i^{th} sample be of size n + 1 and S^2 be its variance (i − 1 2 k) Let σ_i^2 be the population variance of the ith population To test the null hypothesis H_0 $\sigma_1^2 = \sigma_2^2 - \quad - \sigma_k^2$ we use Bartlett s test based on the criterion

$$\chi^2 - \left(n \log_e \sum_{i=1}^{k} \frac{n S^2}{n} \quad \sum_{i\,1}^{k} n \log_e S^2\right) \rightarrow (3\ 1) \text{ where}$$

$$1 + \frac{1}{3(k\ 1)} \sum_{i-1}^{k} \frac{1}{n} \quad \frac{1}{n}$$

$$n - \sum_{I-1}^{k} n$$

The χ^2 given in (3 1) is distributed as a χ^2 variable with k 1 degree of freedom Let $\chi^2_{m\,\alpha}$) be the critical value of χ^2 value such that $Pr(\chi^2_m > \chi^2_{m\,\alpha}) - \alpha$ where χ^2_m is the χ^2 variable with m degree of freedom If the calculated χ^2 value as given in (3·1) is greater than $\chi^2_{k\,1\,\alpha}$ we reject the null hypothesis H_0 $\sigma_1^2 - \sigma_2^2 - \quad \sigma_k^2$ in favour of the alternative hypothesis that not all variances are equal at α level of significance otherwise not

3 2 1 1b Levene s residual F test

Levene (1960) suggested a test for equality of variances of several equalised groups of observations and showed through sampling studies that the test possessed almost unbelievable robustness against departures from normality of the underlying distribution of observations Levene s test is preferable to Bartlett s test which is greatly affected by departures from normality (Box, 1953) Levene also mentioned the possibility of using similar analysis of variance on the absolute value of residuals from other regressions in order to study the variance of the residuals In the present study the residuals e_{ij} were calculated where e_{ij} Y_j $\bar{Y}$ in case of no blocking and $e_{ij} - Y_j$ $\bar{Y}_i$ $Y_j +$ Y when there is blocking Y_{ij} s are the observations $\bar{Y}_i$ and Y_j are the treatment mean and block mean and $\bar{Y}$ is the grand mean

Suppose we have P groups of residuals e_{ij} as follows

Group 1 e_{11} e_{12} e_{1n_1} average e_1 $V(e_1) - \sigma_1^2$

Group 2 e_{21} e_{22} e_{2n_2} average $\bar{e}_2$ $V(e_2) - \sigma_2^2$

Group p e_p e_{p2} e_{pn_p} average $\bar{e}_p$ $V(e_p) - \sigma_p^2$

Costruct from these observations

$$Z \quad |e_{ij} \quad e| \quad j - 1 \; 2 \qquad n$$

$$i = 1 \; 2 \qquad p$$

Perform the standard analysis of variance on Z_j as follows

ANOVA of residuals

Source	df	SS	MS	F
Between groups	p 1	$\sum_{i\,1}^{p} \frac{Z^2}{n} \quad \frac{G^2}{\Sigma n}$	S_1^2	F S_1^2/S^2
Within groups	$\sum_{i=1}^{p} (n \quad 1)$	$\sum_{i}^{p} \sum_{j}^{n} Z_j^2 \quad \sum_{i=1}^{p} \frac{Z^2}{n}$	S^2	
Total	$\sum_{i}^{p} n \quad 1$	$\sum_{j}^{p} \sum_{i}^{n} Z_j^2 \quad \frac{G^2}{\Sigma n}$		

If all the treatments are replicated equal number of times say r n r and Σr – N – rt

If $F_r > F$ [{ (p 1) Σ (n 1) } (1-α)] we say that it is significant and there is evidence that difference exist between σ_1^2 σ_2^2 σp^2 If F is not significant do not reject the null hypothesis $\sigma_1^2 - \sigma_2^2 - \quad - \sigma p^2$

3 2 1 1c Tukey s test of non additivity

In a two way classification model Tukey s test of non additivity is used to decide if row and column effects are additive or not The rationality of the test can be indicated by means of calculus In a two way classification, if effects are exactly additive in the scale of Y we have

$$Y_{ij} \quad Y + (Y_i \quad Y) + \bar{Y}_j \quad Y)$$
$$- \bar{Y} \; [1+\{(Y \quad \bar{Y}) + (\bar{Y}_j \quad Y)\}/ Y]$$
$$- Y \; [1 + \alpha_i + \beta_j]$$

Now let $X_j - Y_j^{1p}$ then

$$X - \bar{Y}^{1p} [1+\alpha + \beta_j]^{p}$$

After using Taylor s expansion and suitable substitutions it can be shown that the first non additive term in the expression would be

$$\frac{(1\ P)}{X} (X \quad \bar{X})(X_j \quad X)$$

This indicates that the residual has a linear regression on the variate

$$(X_i \quad X)(\bar{X}_j \quad X)$$

If X (i = 1 2 t j – 1 2 r) denotes the observations of the two way classification this regression coefficient of the residual $(X_i \quad \bar{X})(\bar{X}_j \quad X)$ can be estimated as

$$B - \frac{\Sigma w \alpha}{D} - \frac{\sum_{i=1}^{t} \sum_{j=1}^{r} X_j \alpha_i \beta_j}{D} \quad \text{where}$$

$$D = (\sum_{i=1}^{t} \alpha^2)(\sum_{j}^{r} \beta_j^2)$$

According to Snedecor and Cochran (1967) the contribution of non additivity to error sum of square with one degree of freedom is given by

$$\frac{N^2}{D} - \frac{(\sum_{1}^{t} w \alpha)^2}{(\sum^{t} \alpha^2)(\sum_{j}^{r} \beta_j^2)}$$

$$= \frac{\left(\sum_{i}^{t} \sum_{j}^{r} X_{ij} \alpha_i \beta_j\right)^2}{(\Sigma \alpha_i^2)(\Sigma \beta_j^2)}$$

This is tested using F test against remainder mean square The relevant analysis of variance table is given below

ANOVA table

Source	df	SS	MS	F
Total	tr 1	ΣX^2 CF		
A (Blocks)	(t 1)	$\frac{\Sigma A^2}{r}$ CF		
B (treatments)	(r 1)	$\frac{\Sigma B^2}{t}$ CF		
Error	(r 1)(t 1)	Subtract		
lack of additivity	1	$\frac{N^2}{D}$	MSLA	$\frac{MSLA}{MSRE}$
Remainder error	(r 1)(t 1)	$\frac{N^2}{D}$ error SS	MSRE	

3 2 1 1d Taylor s power law

This approach consists in fitting a model to decide whether a transformation is necessary and if it is so which transformation is appropriate binomial distribution b value in Taylor s power law will be close to two If it is close to one the underlying distribution is poisson

3 2 1 1e Inverse hyperbolic sine squareroot transformation

Beal (1942) suggested that if standard deviation varied with mean a transformation of the form $x^1 - k^{\prime}$ Sin h^1 $\sqrt{kx}$ where k is a constant and x an observation could be helpful in making standard deviation independent of the mean This was the case with certain types of data where the variance mean relationship would assume a quadratic form In the derivation of the above transformation Beal postulates the variance mean relationship as $\sigma^2 - \mu + k\mu^2 \rightarrow$ (3 2) were σ^2 is the population variance μ the population mean, k is a constant He assumed the charlier coefficient of disturbance for the value of k,

$$k = \frac{\sigma^2 \quad \mu}{\mu^2} \rightarrow (3\ 3)$$

An estimate of k proposed by Beal (1942) is given by

$$k = \frac{\Sigma S^2 \quad \Sigma \quad x}{\Sigma\ x^2}$$

where Σ represents the summation over all pairs S^2 the sample variance and x the sample mean

The estimate of Beal did not posses ~~and~~ any statistical projects apart from its intuitive appeal Hence an attempt was made to get an estimate purely based on statistical theory For this the familiar least square technique was employed The details are as follows

Table 4 Analysis of variance table for testing the breed difference during the first time period

Source	df	Mean sum of squares over various weeks 1	4	8	12
Between breeds	2	2348 82*	25941 67**	47086 43	413352 79
Within breeds	27	484 94	3923 13	19193 97	17521 36

Table 5 Analysis of variance table for testing the breed difference during the second time period

Source	df	Mean sum of squares over various weeks 1	4	8	12
Between breeds	2	127 48	2170 27	15372 38	20540 54
Within breeds	40	463 52	1802 09	5286.53	9002 29

Table 6 Analysis of variance table for testing the breed difference during the third time period

Source	df	Mean sum of squares over various weeks 1	4	8	12
Between breeds	2	1446 27	13163 69	49984 02	121829 64
Within breeds	44	609 09	6654 65	25198 59	39089 49

df degrees of fredom
* significant at 5% level
** significant at 1% level

Table 7 Analysis of variance table for testing the period difference within Newzealand White

Source	df	Mean sum of squares over various weeks			
		1	4	8	12
Between periods	2	1738 48*	9077 48	32138 26	34033 68
Within periods	39	503 95	3905 68	16195 32	23303 88

Table 8 Analysis of variance table for testing the period difference within Soviet Chinchilla

Source	df	Mean sum of squares over various weeks			
		1	4	8	12
Between periods	2	1251 55	11919 83	40203 85	40368.56
Within periods	34	546 65	4492 47	17138 42	21902 05

Table 9 Analysis of variance table for testing the period difference within Grey Giant

Source	df	Mean sum of squares over various weeks			
		1	4	8	12
Between periods	2	6174 00**	25175 54**	42742 90	143128 07**
Within periods	38	533 27	4392 23	16583 49	23912 91

df degrees of fredom
* significant at 5% level
** significant at 1% level

Table 10 Parameters of linear model fitted to average weekly body weights of different breeds of rabbits for the three time periods

Breed	a	b	R^2	s
First time period October to January				
NWM	30 38	109 32	0 998	17 60
NWF	-40 05	101 73	0 996	25 49
NW	35 75	105 11	0 997	19 90
SCM	18 83	111 18	0 998	17.24
SCF	0 25	107 87	0 999	9 98
SC	8 69	109 37	0 999	10.58
GGM	31 92	107 47	0 999	14 78
GGF	41 04	108 64	0 998	16 75
GG	36 48	108 06	0 999	14 72
Second time period February to May				
NWM	17 21	113 18	0 998	18.51
NWF	11 31	111 76	0 998	19 85
NW	4 99	112 57	0 999	11 97
SCM	18 50	106.47	0 999	11.28
SCF	3 87	108 54	0 999	13.54
SC	5 71	107 66	0 999	12 43
GGM	8 64	105 22	0 999	14 13
GGF	0 32	106.99	0 998	14 44
GG	3 86	106.16	0 998	14.23
Third Time Period June to September				
NWM	8 63	110 14	0 995	29 49
NWF	10 20	107 07	0 998	20 47
NW	0 26	108 77	0 997	23 79
SCM	36 70	111 68	0 999	14 90
SCF	7 79	95 04	0 997	19.55
SC	1 68	109 27	0 998	15 40
GGM	19 37	98 37	0 994	28 92
GGF	17 64	95 23	0 999	12.22
GG	1 95	96 94	0 997	20 67

NWM Newzealand White (male)
NWF Newzealand White (female)
NW Newzealand White Irrespective of sex
SCM Soviet Chinchilla (male)
SCF Soviet Chinchilla (female)
SC Soviet Chinchilla Irrespective of sex
GGM Grey Giant (male)
GGF Grey Giant (female)
GG Grey Giant Irrespective of sex

Table 11 Parameters of quadratic model fitted to average weekly body weights of different breeds of rabbits for the three time periods

Breed	a	b_1	b_2	R^2	s
First time period October to January					
NWM	11 64	101 29	0 62	0 998	16 96
NWF	19 23	76 32	1 95	0 999	12 46
NW	5 51	87 42	1 36	0 999	12 87
SCM	6 51	122 04	0 84	0 999	15 05
SCF	6 31	105 27	0 20	0 999	10.24
SC	0 48	112 89	0 27	0 999	10 66
GGM	17 14	113 80	0 49	0 999	14 41
GGF	12 05	121 07	0 96	0 999	13 28
GG	14 59	117 44	-0 72	0 999	12 79
Second time period February to May					
NWM	5 59	122 98	0 75	0 999	17.29
NWF	33 90	92 65	1 46	0 999	11.30
NW	11 10	109 98	0 20	0 999	12.39
SCM	39 80	97 47	0 69	0 999	8 52
SCF	22 38	97 45	0 85	0 999	9 96
SC	29 84	97 46	0 78	0 999	9 12
GGM	28 83	95 61	0 81	0 999	11 42
GGF	26 27	95 75	0 86	0 999	11 15
GG	31 77	95 44	0 74	0 999	11 86
Third Time Period June to September					
NWM	35 11	128 88	1 44	0 997	25 66
NWF	19 62	111 10	0 31	0 998	21.24
NW	28 22	120 98	-0 94	0 997	22.32
SCM	19 32	119 13	-0 57	0 997	21 24
SCF	-8 70	95 43	-0 03	0 997	20 60
SC	11 70	113 56	0 33	0 999	15 72
GGM	55 96	114 05	1 21	0 995	26 71
GGF	2 49	101 82	0 50	0 999	11.36
GG	28 46	108 29	-0 87	0 998	19 01

NWM Newzealand White (male)
NWF Newzealand White (female)
NW Newzealand White Irrespective of sex
SCM Soviet Chinchilla (male)
SCF Soviet Chinchilla (female)
SC Soviet Chinchilla Irrespective of sex
GGM Grey Giant (male)
GGF Grey Giant (female)
GG Grey Giant Irrespective of sex

Table 12 Parametersof von bertalanffy fitted to average weekly body weights of different breeds of rabbits for the three time periods

Breed	a	b	k	R^2	s
First time period October to January					
NWM	2900	0 7117	-0 0925	0 998	15 96
NWF	2900	0 7207	-0 0870	0 999	7 59
NW	2900	0 7165	-0 0918	0 999	8 80
SCM	2860	0 6759	-0 0940	0 996	23 27
SCF	2860	0 6895	-0 0918	0 998	16 51
SC	2860	0 6831	-0 0928	0 998	18 53
GGM	3000	0 6690	-0 0867	0 997	22 04
GGF	3000	0 6630	-0 0875	0 996	24 97
GG	3000	0 6660	-0 0871	0 996	23 01
Second time period February to May					
NWM	2900	0 6777	-0 0944	0 996	25 72
NWF	2900	0 6951	-0 0935	0 999	2 76
NW	2900	0 6840	-0 0939	0 998	14 82
SCM	2860	0 6738	-0 0898	0 999	7 81
SCF	2860	0 6898	-0 0920	0 999	7 66
SC	2860	0 6828	-0 0911	0 999	7 50
GGM	3000	0 6833	-0 0854	0 999	9 79
GGF	3000	0 6930	-0 0869	0 999	8 81
GG	3000	0 6865	-0 0862	0 999	9 20
Third Time Period June to September					
NWM	2900	0 685	-0 092	0 992	35 34
NWF	2900	0 698	-0 090	0 996	24 63
NW	2900	0 691	-0 091	0 994	29 85
SCM	2860	0 663	-0 094	0 997	22 77
SCF	2860	0 703	-0 083	0 993	27 82
SC	2860	0 690	-0 093	0 997	19 91
GGM	3000	0 685	-0 079	0 995	24 25
GGF	3000	0 715	-0 083	0 988	38 28
GG	3000	0 700	-0 081	0 992	31 06

NWM Newzealand White (male)
NWF Newzealand White (female)
NW Newzealand White Irrespective of sex
SCM Soviet Chinchilla (male)
SCF Soviet Chinchilla (female)
SC Soviet Chinchilla Irrespective of sex
GGM Grey Giant (male)
GGF Grey Giant (female)
GG Grey Giant Irrespective of sex

Table 13 Parameters of exponential model fitted to average weekly body weights of different breeds of rabbits for the three time periods

Breed	a	b	R^2	s
First time period October to January				
NWM	144 03	0 205	0 923	1 25
NWF	131 63	0 205	0 937	1 22
NW	137 00	0 205	0 932	1 23
SCM	175 91	0 191	0 902	1 27
SCF	142 59	0 207	0 920	1.26
SC	167 34	0 193	0 905	1 27
GGM	184 93	0 183	0 916	1 23
GGF	190 57	0 183	0 905	1 25
GG	188 67	0 182	0 911	1 24
Second time period February to May				
NWM	176.97	0 193	0 898	1 28
NWF	168 51	0 192	0 941	1 20
NW	173 64	0 192	0 918	1 24
SCM	180 19	0 183	0 934	1 20
SCF	165 34	0 192	0 931	1 22
SC	171 57	0 188	0 932	1 21
GGM	171 06	0 187	0 936	1 20
GGF	166.50	0 190	0 934	1 21
GG	168 68	0 189	0 935	1 21
Third Time Period June to September				
NWM	165 67	0 196	0 903	1 27
NWF	151 41	0 200	0 916	1 26
NW	159 17	0 198	0 909	1 27
SCM	192 48	0 184	0 907	1 25
SCF	134 29	0 201	0 906	1 27
SC	160 77	0 197	0 913	1 26
GGM	126.47	0 209	0 901	1 30
GGF	154 47	0 189	0 913	1 25
GG	139 77	0 199	0 907	1 27

NWM Newzealand White (male)
NWF Newzealand White (female)
NW Newzealand White Irrespective of sex
SCM Soviet Chinchilla (male)
SCF Soviet Chinchilla (female)
SC Soviet Chinchilla Irrespective of sex
GGM Grey Giant (male)
GGF Grey Giant (female)
GG Grey Giant Irrespective of sex

Table 14 Parameters of modified exponential fitted to average weekly body weights of different breeds of rabbits for the three time periods

Breed	k	a	b	R^2	s
First time period October to January					
NWM	19132 31	19215 72	1 01	0 998	121 52
NWF	1830 93	1930 26	1 04	0 999	116.06
NW	3584 04	3676 58	1 03	0 999	117 93
SCM	7000 05	-6890 93	0 98	0 999	122 28
SCF	11341.57	11456 89	1 01	0 999	119 51
SC	33446 77	33333 4	1 00	0 999	120 92
GGM	17064 78	16936 68	0 99	0 999	119 32
GGF	7430.56	7299 37	0 98	0 999	119 33
GG	10199 94	10070 4	0 99	0 999	119 04
Second time period February to May					
NWM	8087.50	7973 98	0 985	0 999	124 46
NWF	3860 40	3982 88	1 025	0 999	125 78
NW	-8935 38	9068 82	1 011	0 999	118 28
SCM	8030 495	8144 90	1 013	0 999	120 91
SCF	6525 76	6650 42	1 015	0 999	117 70
SC	6585 28	6703 43	1 010	0 999	119 47
GGM	69807 04	9927 09	1 002	0 999	126.78
GGF	-8390 93	8513 47	1 012	0 999	119 74
GG	6557 65	6678 82	1 015	0 999	118 63
Third Time Period June to September					
NWM	3069 22	3006 03	0 953	0 995	123 75
NWF	6352 74	-6276 56	0 981	0 997	118 81
NW	3834.33	3765 13	0 976	0 996	121 15
SCM	8242 74	-8113 64	0 985	0 999	123 06
SCF	4292 46	-4227 81	0 974	0 996	105 99
SC	12925 72	12830 99	0 991	0 999	120 82
GGM	4257 11	-4211 68	0 973	0 995	111 17
GGF	8515 63	-8417 21	0 988	0 999	105 14
GG	5430 19	5359 76	0 980	0 998	108 00

NWM Newzealand White (male)
NWF Newzealand White (female)
NW Newzealand White Irrespective of sex
SCM Soviet Chinchilla (male)
SCF Soviet Chinchilla (female)
SC Soviet Chinchilla Irrespective of sex
GGM Grey Giant (male)
GGF Grey Giant (female)
GG Grey Giant Irrespective of sex

Table 15 Parameters of logistic model fitted to average weekly body weights of different breeds of rabbits for the three time periods

Breed	k	a	b	R^2	s
First time period October to January					
NWM	0 4268	1310 13	9.50	0 980	113 42
NWF	0 3865	1303 62	9 82	0 980	102 53
NW	0 4048	1301 25	9 62	0 980	107 19
SCM	0 4297	1353 41	8 17	0 983	112 93
SCF	0 4168	1332 85	8 72	0 981	110 84
SC	0 4225	1341 69	8 45	0 982	111 56
GGM	0 4014	1361 42	7 46	0 985	111 39
GGF	0 4089	1365 45	7.38	0 986	108 92
GG	0 4051	1363 41	7 41	0 986	110 06
Second time period February to May					
NWM	0 4318	1373 61	8.31	0 981	115 41
NWF	0 3772	1451 33	8.39	0 986	115 17
NW	0 3768	1385 91	7 49	0 986	110 06
SCM	0.3945	1370 79	8 29	0 984	112 72
SCF	0 3772	1370 85	7 81	0 988	107 90
SC	0 3856	1372 32	8 14	0 986	110 11
GGM	0 4078	1399 81	8 26	0 983	115 03
GGF	0 3867	1377 46	7 93	0 985	111 54
GG	0 3817	1371 66	7 99	0 987	109 06
Third Time Period June to September					
NWM	0 463	1281 03	8.52	0 979	117 35
NWF	0 438	1268.32	8 84	0 981	110 84
NW	0 452	1274 01	8 65	0 980	114 32
SCM	0 419	1381 36	7 47	0 977	119 85
SCF	0 458	1095 17	8 93	0 967	105 61
SC	0 428	1324 46	8 68	0 984	112.27
GGM	0 473	1135 16	10 08	0 984	114 32
GGF	0 417	1178 87	7 90	0 984	102 51
GG	0 446	1155 06	8 93	0 985	100 34

NWM Newzealand White (male)
NWF Newzealand White (female)
NW Newzealand White Irrespective of sex
SCM Soviet Chinchilla (male)
SCF Soviet Chinchilla (female)
SC Soviet Chinchilla Irrespective of sex
GGM Grey Giant (male)
GGF Grey Giant (female)
GGM Grey Giant Irrespective of sex

Table 16 Parameters of gompertz model fitted to average weekly body weights of different breeds of rabbits for the three time periods

Breed	k	a	b	R^2	s
First time period October to January					
NWM	0 1896	1756.23	2 70	0 996	112.15
NWF	0 1527	2023 71	2 83	0 998	105 87
NW	0 1697	1868 62	2 76	0 998	108 15
SCM	0 2007	1717 18	2 48	0 997	112.99
SCF	0 1809	1813 35	2.58	0 997	110 28
SC	0 1899	1763 5	2.53	0 997	111 20
GGM	0 1855	1770 68	2 43	0 998	111 43
GGF	0 1920	1739 53	2.38	0 998	110 33
GG	0 1887	1754 46	2 40	0 998	110 76
Second time period February to May					
NWM	0 2003	1749 71	2 48	0 996	114 86
NWF	0 1598	2096.59	2 64	0 998	117 00
NW	0 1668	1906.95	2 48	0 998	110 74
SCM	0 1727	1890 06	2 58	0 997	112 75
SCF	0 1649	1910.57	2 54	0 998	109 68
SC	0 1680	1911 04	2.58	0 998	111 25
GGM	0 1828	1866.53	2 54	0 997	115 19
GGF	0 1701	1897 65	2 54	0 998	111 87
GG	0 1666	1910 83	2 56	0 998	110 50
Third Time Period June to September					
NWM	0 233	1529 91	2 53	0 993	116.05
NWF	0 207	1601 65	2 59	0 995	110 11
NW	0 222	1555 71	2 55	0 994	113 09
SCM	0 197	1755 83	2 40	0 995	116.63
SCF	0 219	1361 04	2 57	0 988	100 99
SC	0 196	1713 89	2 57	0 997	111 91
GGM	0 224	1404 58	2 71	0 997	101 88
GGF	0 194	1512 23	2 47	0 997	98 11
GG	0 210	1451 74	2 58	0 997	99 88

NWM Newzealand White (male)
NWF Newzealand White (female)
NW Newzealand White Irrespective of sex
SCM Soviet Chinchilla (male)
SCF Soviet Chinchilla (female)
SC Soviet Chinchilla Irrespective of sex
GGM Grey Giant (male)
GGF Grey Giant (female)
GG Grey Giant Irrespective of sex

Table 17 **Body length and body girth of Newzealand White, Soviet Chinchilla and Grey Giant Rabbits**

Age in weeks	Newzealand White		Soviet Chinchilla		Grey Giant	
	Length (cm)	Girth (cm)	Length (cm)	Girth (cm)	Length (cm)	Girth (cm)
1	10 9	12 31	10 17	12 58	10 17	12 58
2	13 6	15 25	12 67	14 5	12 67	14 50
3	17 2	19 46	15 42	17 25	15 42	17 25
4	18 6	19 88	17 50	19 25	17 50	19 25
5	21 6	21 96	19 50	21 33	19 50	21 33
6	22 1	23 27	24 08	24 42	23 83	24 42
7	23 2	24 46	24 50	25 17	24 08	25 17
8	24 7	25 46	23 83	25 67	24 50	25 67
9	25 8	26 85	24 67	26 00	24 67	26 00
10	27 2	27 77	25 67	27 50	25 67	27 50
11	27 7	29 23	26 17	28 17	26 17	28 17
12	28 7	29 18	27 00	29 50	27 00	29 50

Table 18 Climatological data and corresponding THI in the three time periods

Week	MT	DBT	WBT	THI
First time period October to January				
1	27 5	30 8	25.3	80 99
2	27 9	30 7	26 1	81 49
3	27 6	30 5	25 7	81 06
4	28 0	31 5	25 6	81 71
5	28 4	33 0	26.5	83 44
6	28 8	30 2	26 3	81 28
7	27 5	28 5	25 6	79 55
8	26 1	30 5	26 7	81 76
9	26 8	31 0	25.5	81 28
10	27 3	31 9	24 1	80 92
11	26.5	32.3	23 9	81 06
12	27 4	31 8	22 8	79 91
Second time period February to May				
1	27 8	33 4	22 1	80 50
2	28 6	34 5	21 9	81 20
3	29 0	34 7	23 8	82 72
4	29 5	35 3	22 0	81 85
5	29 8	37 0	21 1	82 43
6	29 9	36 1	24 1	83 94
7	31 0	35 7	26.5	85.38
8	30 9	34 0	27 0	84.52
9	30 0	34 0	27 1	84.59
10	30 9	33 6	26 6	83 94
11	29 7	33 0	26 4	83 36
12	29 1	33 1	27 1	83 94
Third time period June to September				
1	29 3	30 1	26 3	81 21
2	26 8	27 8	25 8	79 19
3	26 3	28 3	25 5	79 34
4	27 1	28 1	26 1	79 62
5	27 5	28 3	25 3	79 19
6	25 9	26 9	25 0	77 97
7	26 2	27 9	25 3	78 90
8	26 5	28 3	25 4	79 26
9	26 4	28 7	25 5	79 62
10	27 5	29 7	25 9	80 63
11	27 6	29 4	25 8	80 34
12	27 4	28 5	25 7	79 62

MT Mean temperature DBT Dry bulb temprature
WBT Wet bulb temperature THI Temperature Humidity Index

Table 19 Correlation coefficients between weight gain and THI

Breed \ Period	Oct. to Jan	Feb to May	June to Sept
Newzealand White	0 689*	0 149	0 711**
Soviet Chinchilla	0 638*	0 084	0 779**
Grey Giant	0 601*	0 002	0 845**

* Significant at 5% level ** Significant at 1% level

Table 20 Relatıve humıdıty and temperature ın the three tıme perıods on weekly basıs

Week	RH	Temp
First tıme perıod October to January		
1	67 5	27 5
2	64 4	27 9
3	70 5	27 6
4	62 2	28 0
5	60 4	28 4
6	66 2	28 8
7	73 1	27 5
8	76 2	26 1
9	67 4	26 8
10	60 1	27 3
11	42 0	26 5
12	48 1	27 4
Second tıme perıod February to May		
1	31 4	27 8
2	33 7	28 6
3	29 7	29 0
4	40 0	29 5
5	28 0	29 8
6	20 7	29 9
7	31 1	31 0
8	46 4	30 9
9	55 7	30 0
10	60 7	30 9
11	54 5	29 7
12	57 3	29 1
Thırd tıme perıod June to September		
1	68 2	29 3
2	80 4	26 8
3	80 1	26 3
4	81 2	27 1
5	79 7	27 5
6	87 2	25 9
7	83 4	26 2
8	74 8	26 5
9	80 5	26 4
10	74 8	27 5
11	71 0	27 6
12	77 4	27 4

RH Relatıve Humıdıty Temp Temperature

FIG 1 RELATIONSHIP BETWEEN AGE AND BODY WEIGHTS OF NEWZEALAND WHITE SOVIET CHINCHILLA AND GREY GIANT RABBITS(MALE) DURING THE PERIOD OCTOBER TO JANUARY

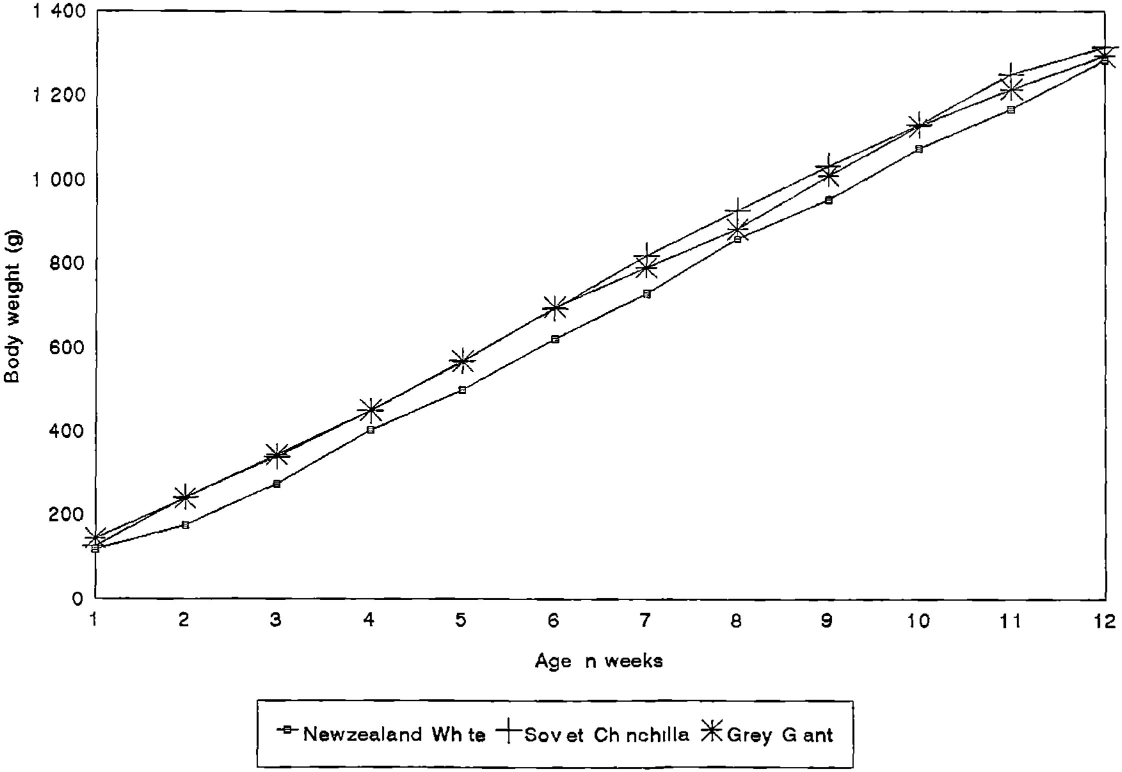


FIG 2 RELATIONSHIP BETWEEN AGE AND BODY WEIGHTS OF NEWZEALAND WHITE SOVIET CHINCHILLA AND GREY GIANT RABBITS(FEMALE) DURING THE PERIOD OCTOBER TO JANUARY

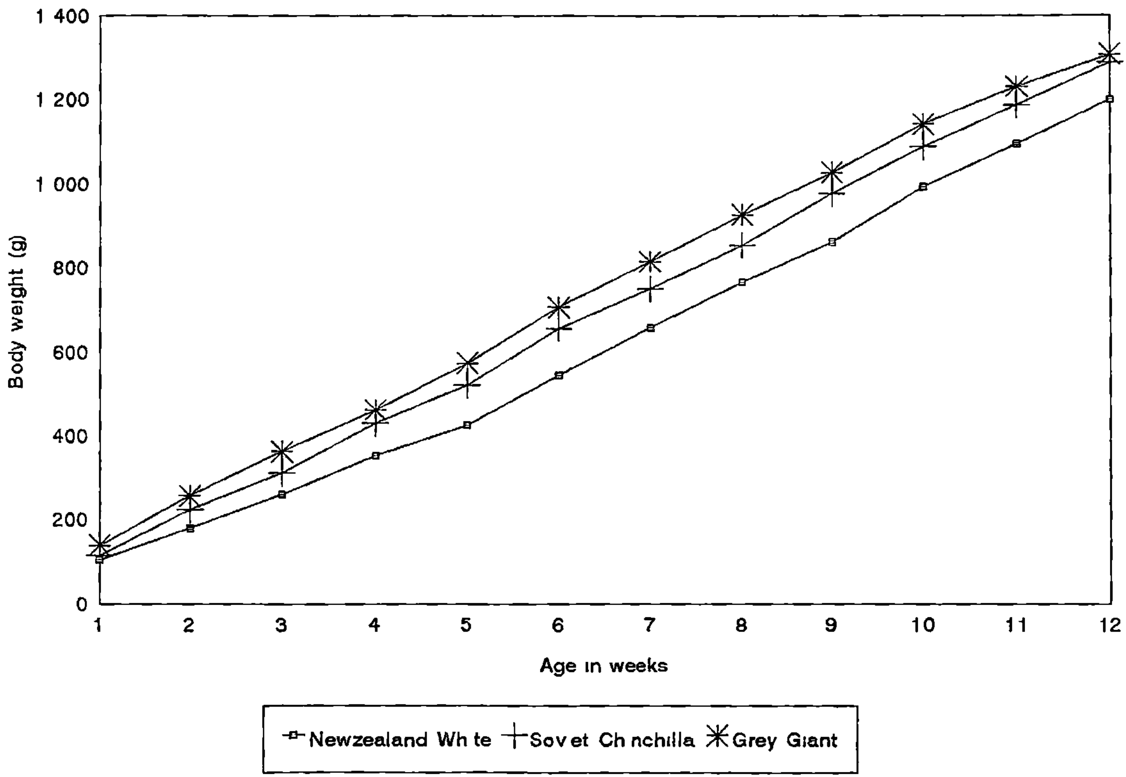


FIG 3 RELATIONSHIP BETWEEN AGE AND BODY WEIGHT OF NEWZEALAND WHITE SOVIET CHINCHILLA AND GREY GIANT RABBITS(IRRESPECTIVE OF SEX) DURING THE PERIOD OCTOBER TO JANUARY

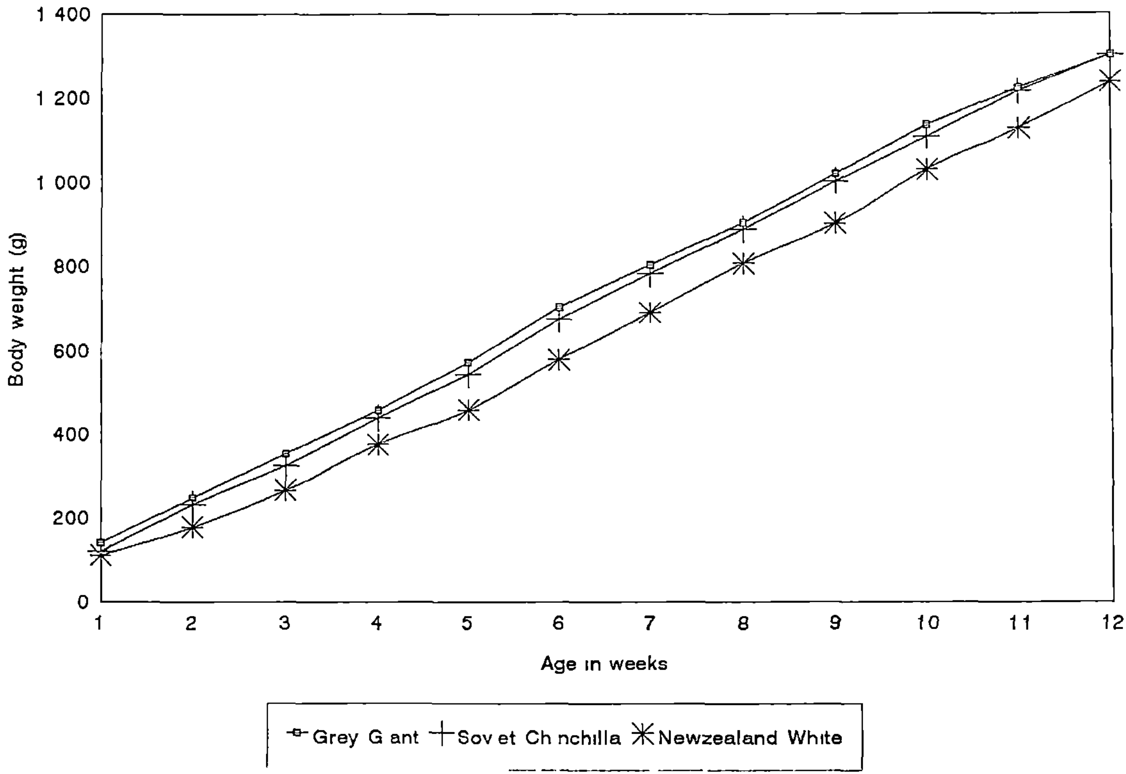


Fig 4 RELATIONSHIP BETWEEN AGE AND BODY WEIGHT OF NEWZEALAND WHITE SOVIET CHINCHILLA AND GREY GIANT RABBITS(MALE) FOR THE PERIOD JUNE TO SEPTEMBER

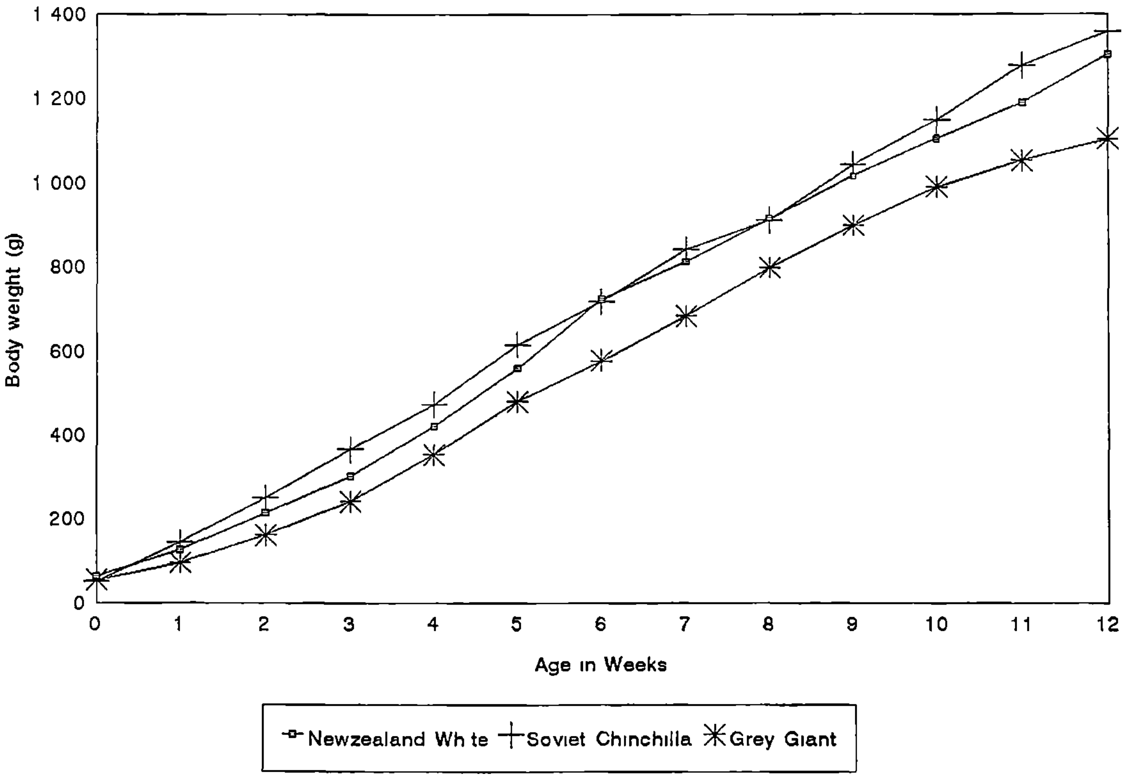


Fig 5 RELATIONSHIP BETWEEN AGE AND BODY WEIGHT OF NEWZEALAND WHITE SOVIET CHINCHILLA AND GREY GIANT RABBITS (FEMALE) FOR THE PERIOD JUNE TO SEPTEMBER

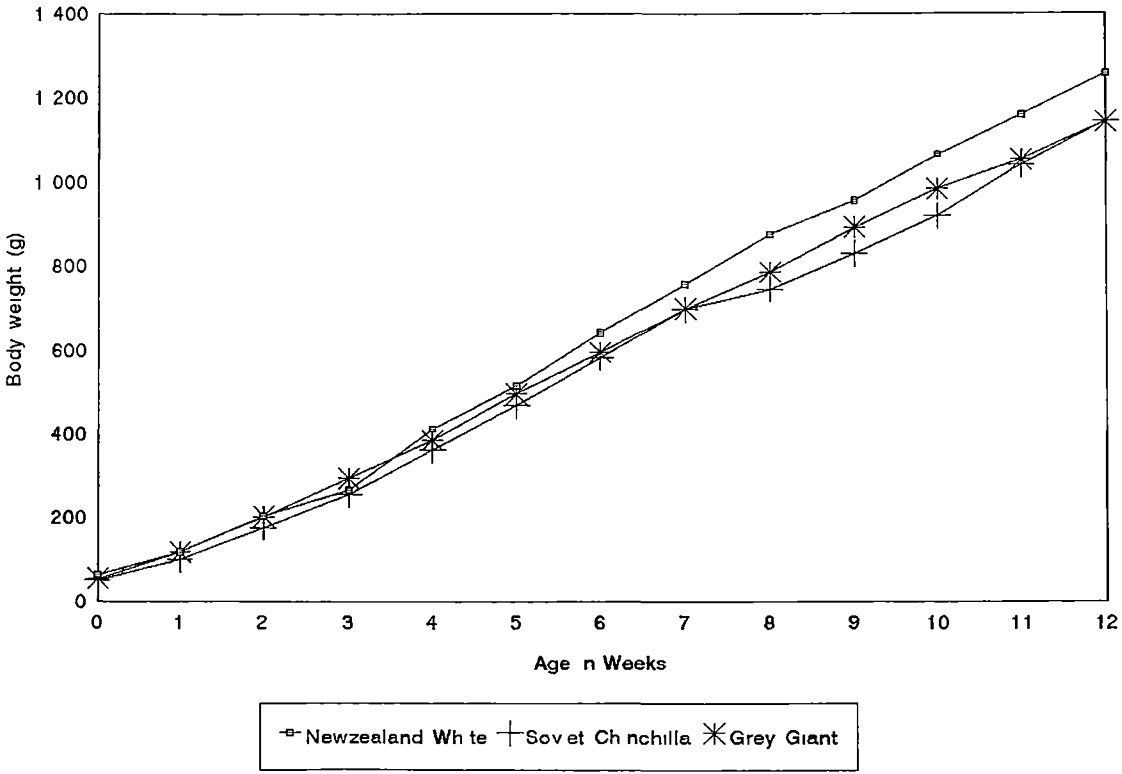


Fig 6 RELATIONSHIP BETWEEN AGE AND BODY WEIGHT OF NEWZEALAND WHITE SOVIET CHINCHILLA AND GREY GIANT RABBITS IRRESPECTIVE OF SEX FOR THE PERIOD JUNE TO SEPTEMBER

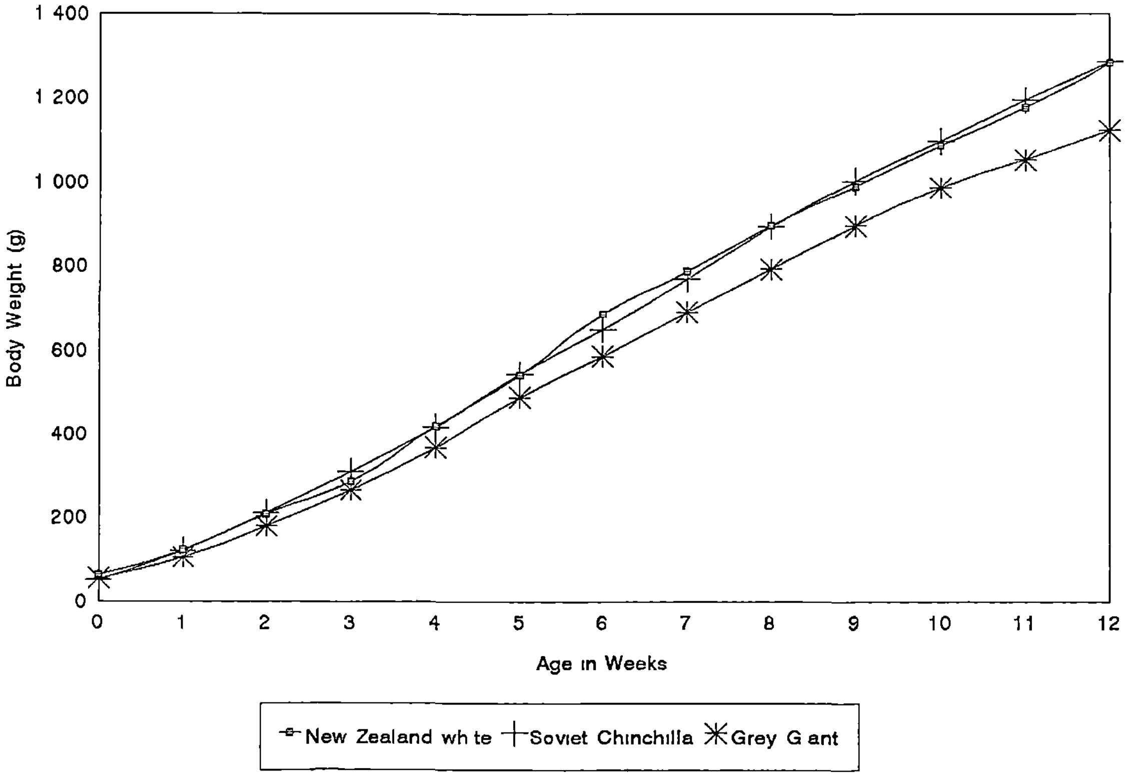


FIG 7 RELATIONSHIP BETWEEN AGE AND BODY WEIGHTS OF NEWZEALAND WHITE SOVIET CHINCHILLA AND GREY GIANT RABBITS(MALE) DURING THE PERIOD FEBRUARY TO MAY

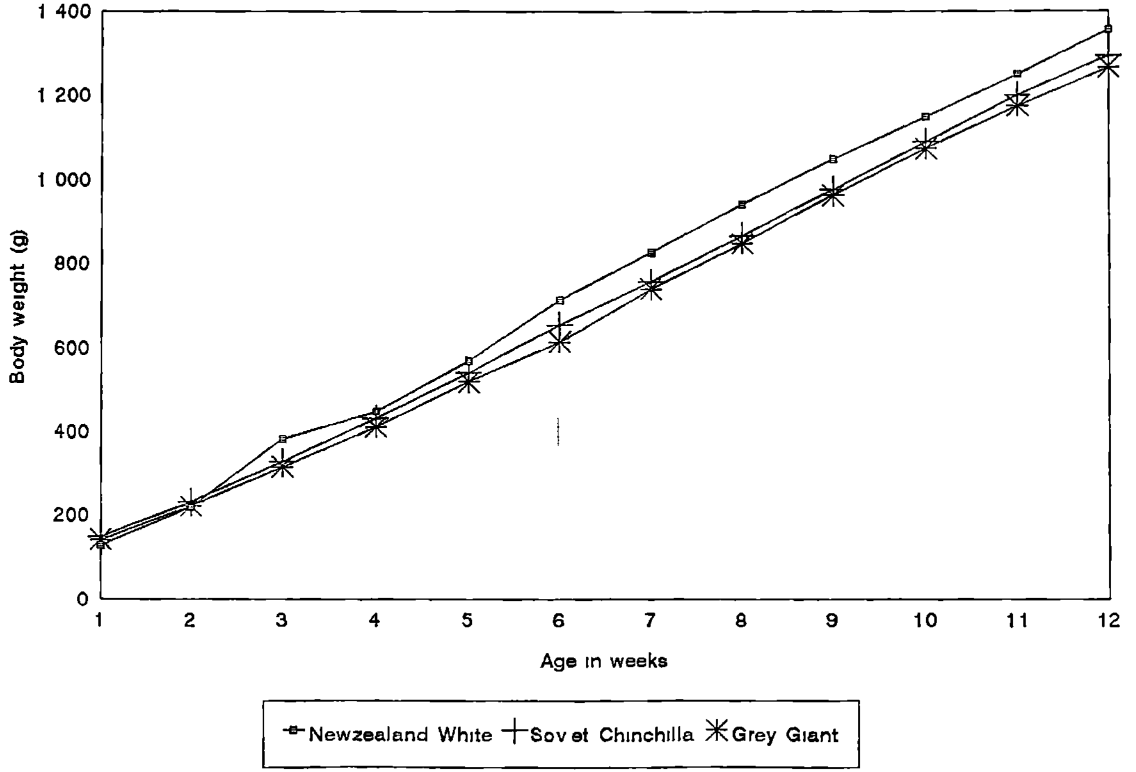


FIG 8 RELATIONSHIP BETWEEN AGE AND BODY WEIGHTS OF NEWZEALAND WHITE SOVIET CHINCHILLA AND GREY GIANT RABBITS(FEMALE) DURING THE PERIOD FEBRUARY TO MAY

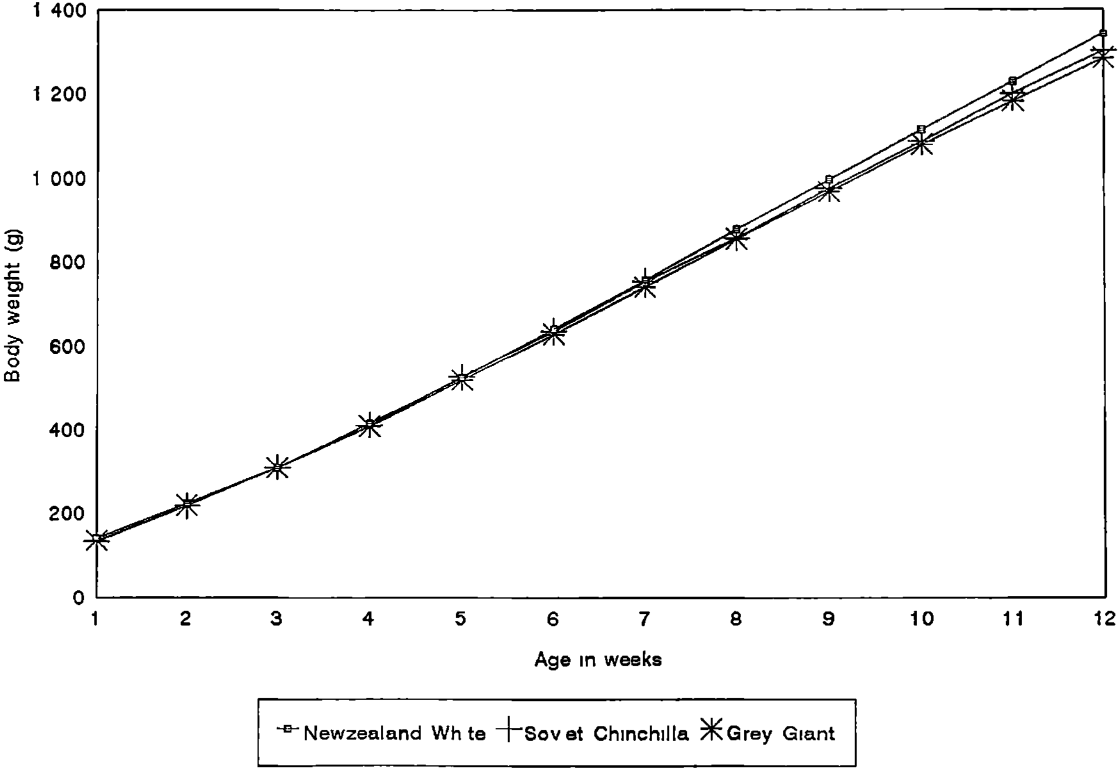


FIG 9 RELATIONSHIP BETWEEN AGE AND BODY WEIGHTS OF NEWZEALAND WHITE SOVIET CHINCHILLA AND GREY GIANT RABBITS(IRRESPECTIVE OF SEX) DURING THE PERIOD FEBRUARY TO MAY

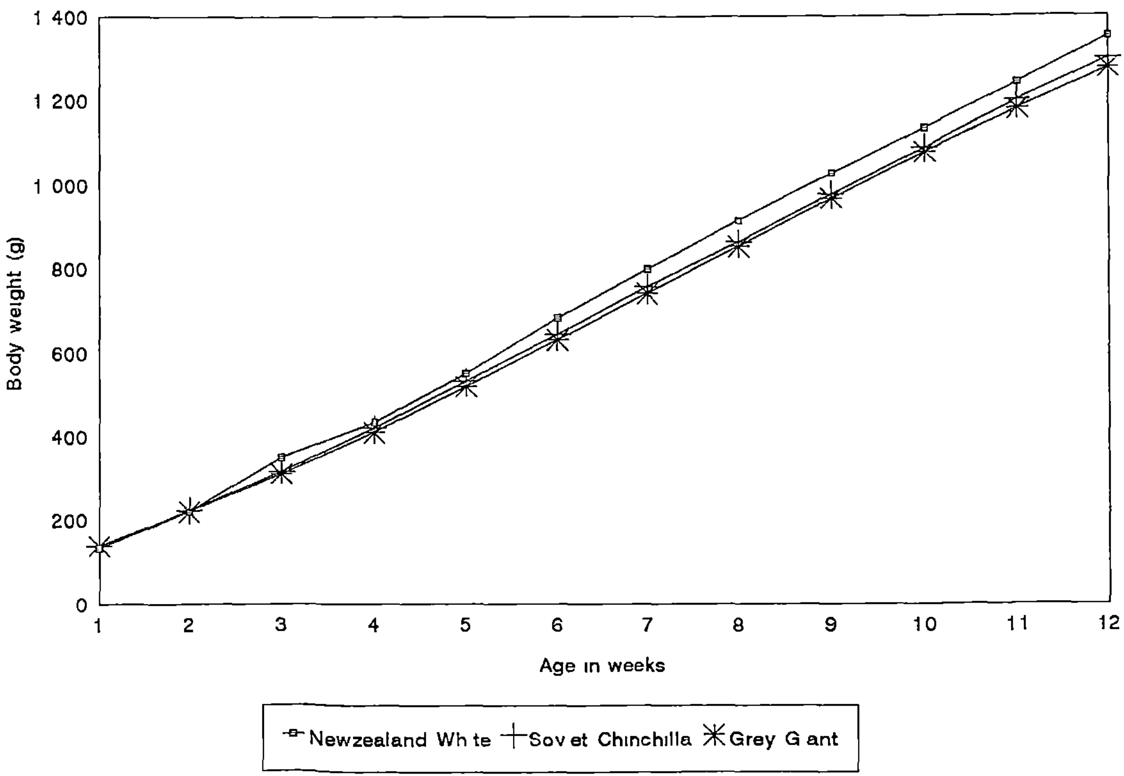


Fig 10 GROWTH MODELS FITTED TO BODY WEIGHTS OF NEWZEALAND WHITE DURING THE PERIOD OCTOBER TO JANUARY

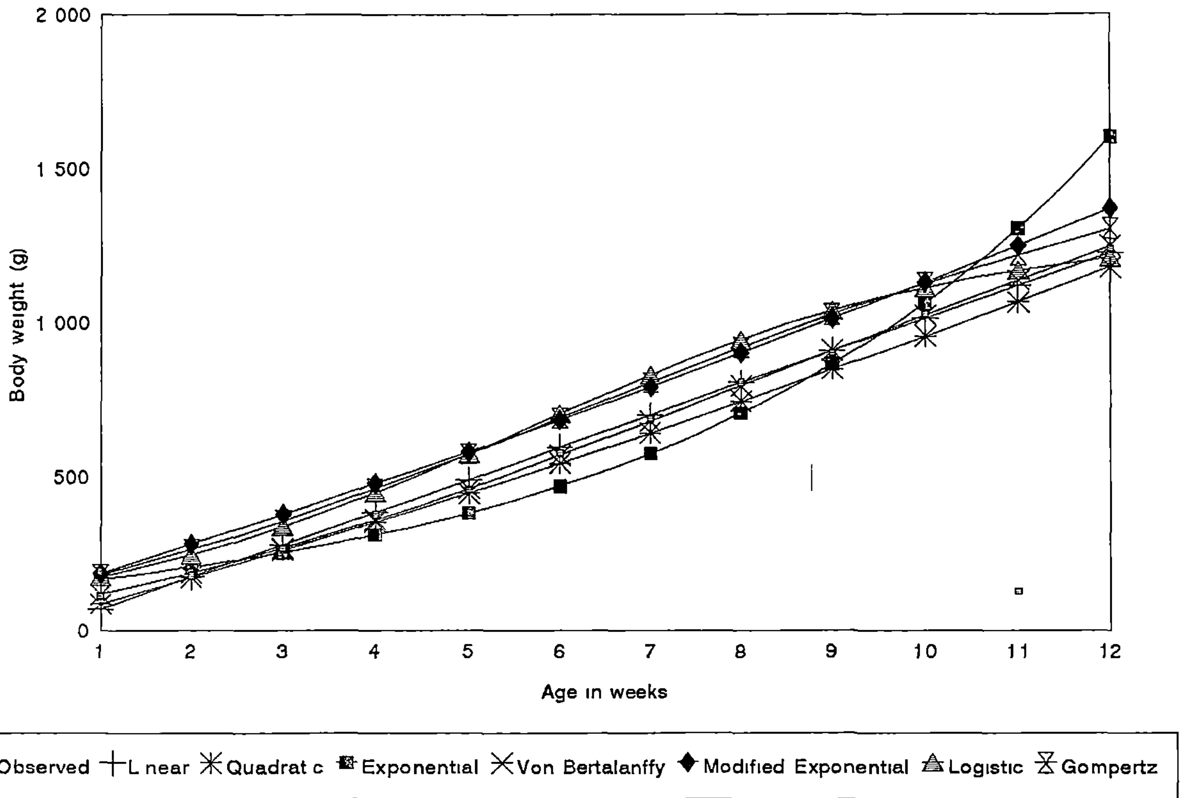


FIG 11 GROWTH MODELS FITTED TO BODY WEIGHTS OF SOVIET CHINCHILLA DURING THE PERIOD OCTOBER TO JANUARY

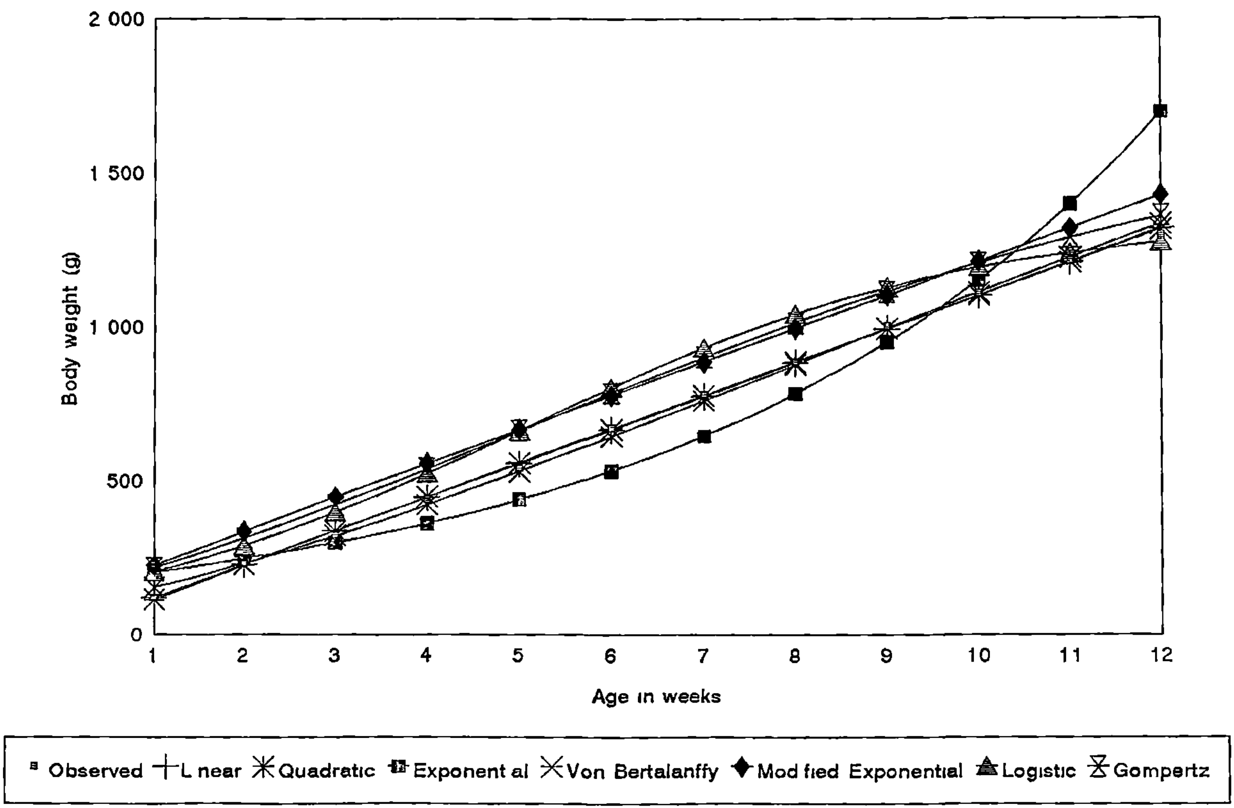


Fig 12 SEVEN GROWTH MODELS FITTED TO BODY WEIGHTS OF GREY GIANT DURING THE PERIOD OCTOBER TO JANUARY

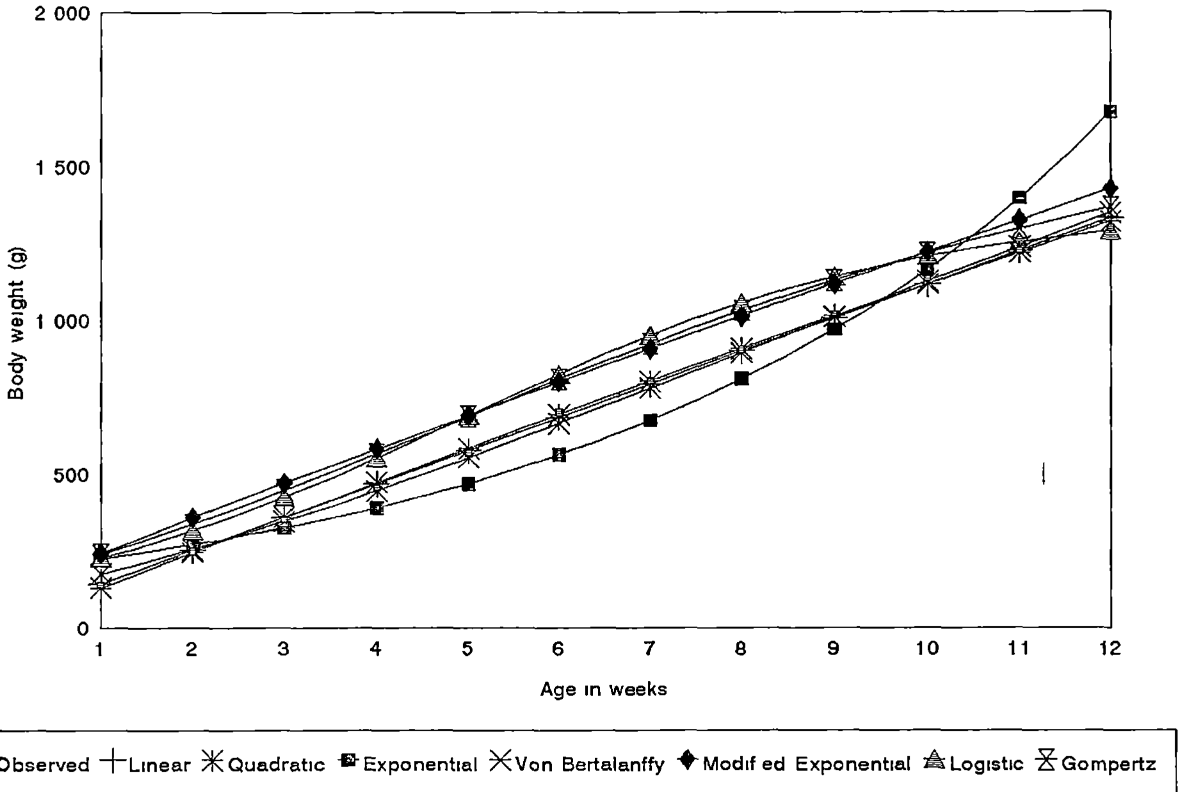


Fig 13 GROWTH MODELS FITTED TO BODY WEIGHTS OF NEWZEALAND WHITE DURING THE PERIOD FEBRUARY TO MAY

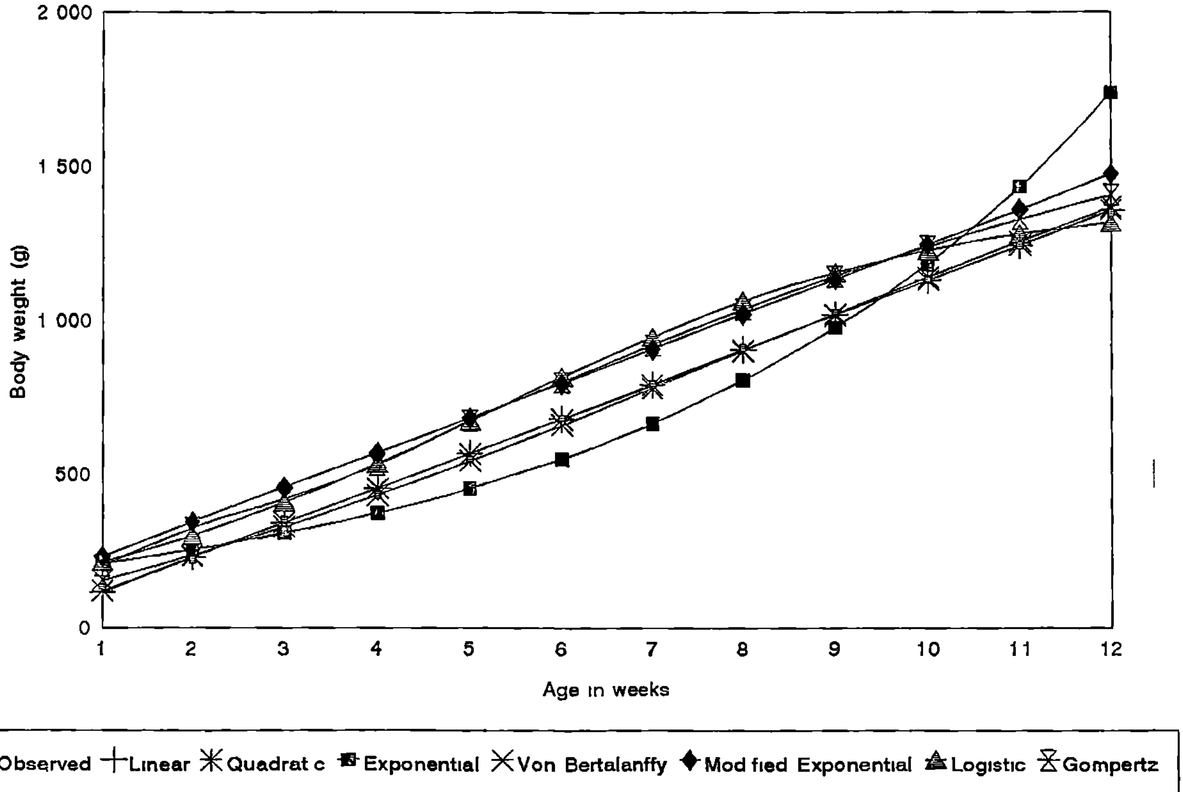


FIG 14 GROWTH MODELS FITTED TO BODY WEIGHTS OF SOVIET CHINCHILLA DURING THE PERIOD FEBRUARY TO MAY

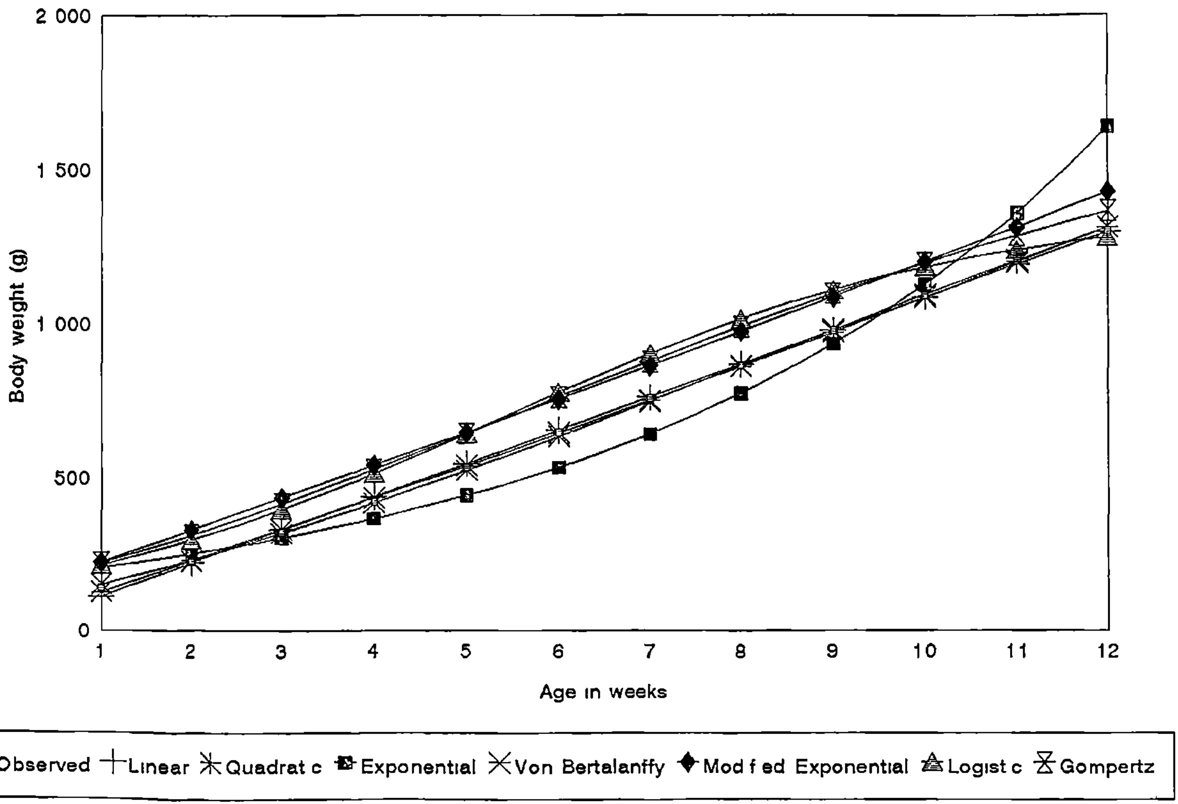


FIG 15 GROWTH MODELS FITTED TO BODY WEIGHTS OF GREY GIANT DURING THE PERIOD FEBRUARY TO MAY

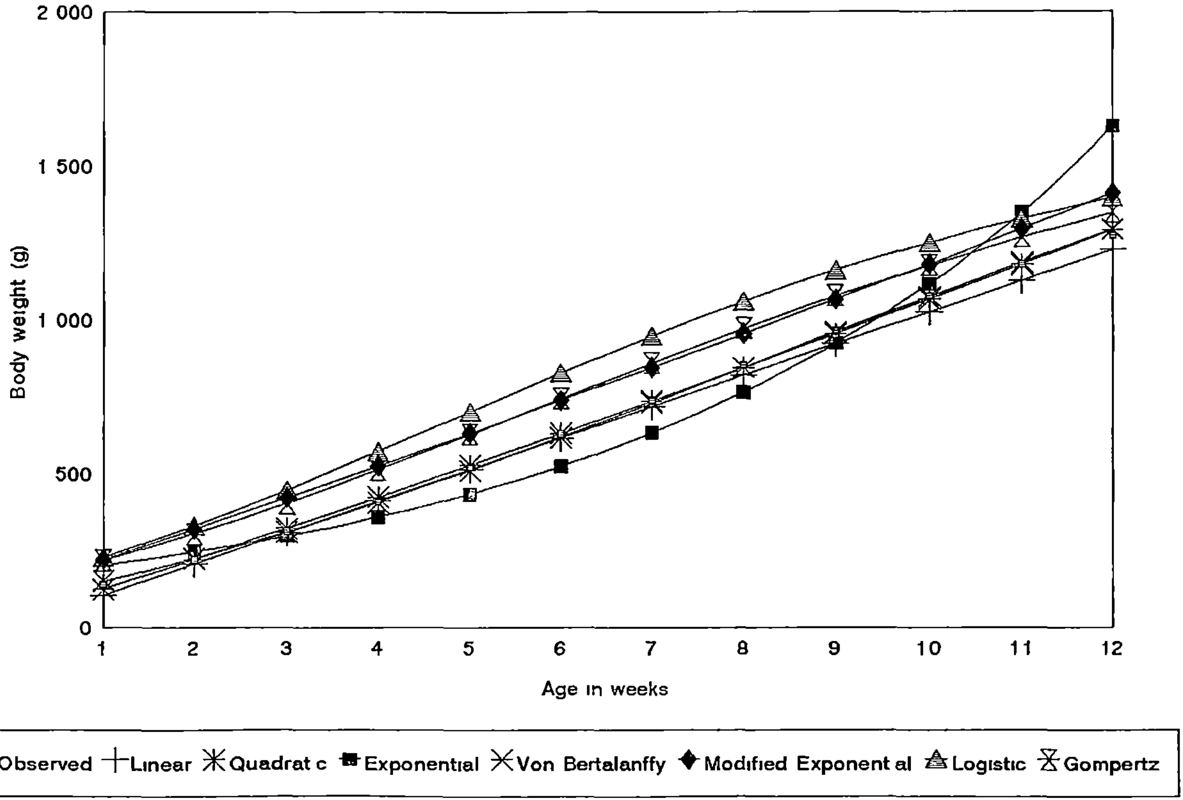


FIG 16 GROWTH MODELS FITTED TO BODY WEIGHTS OF NEWZEALAND WHITE DURING THE PERIOD JUNE TO SEPTEMBER

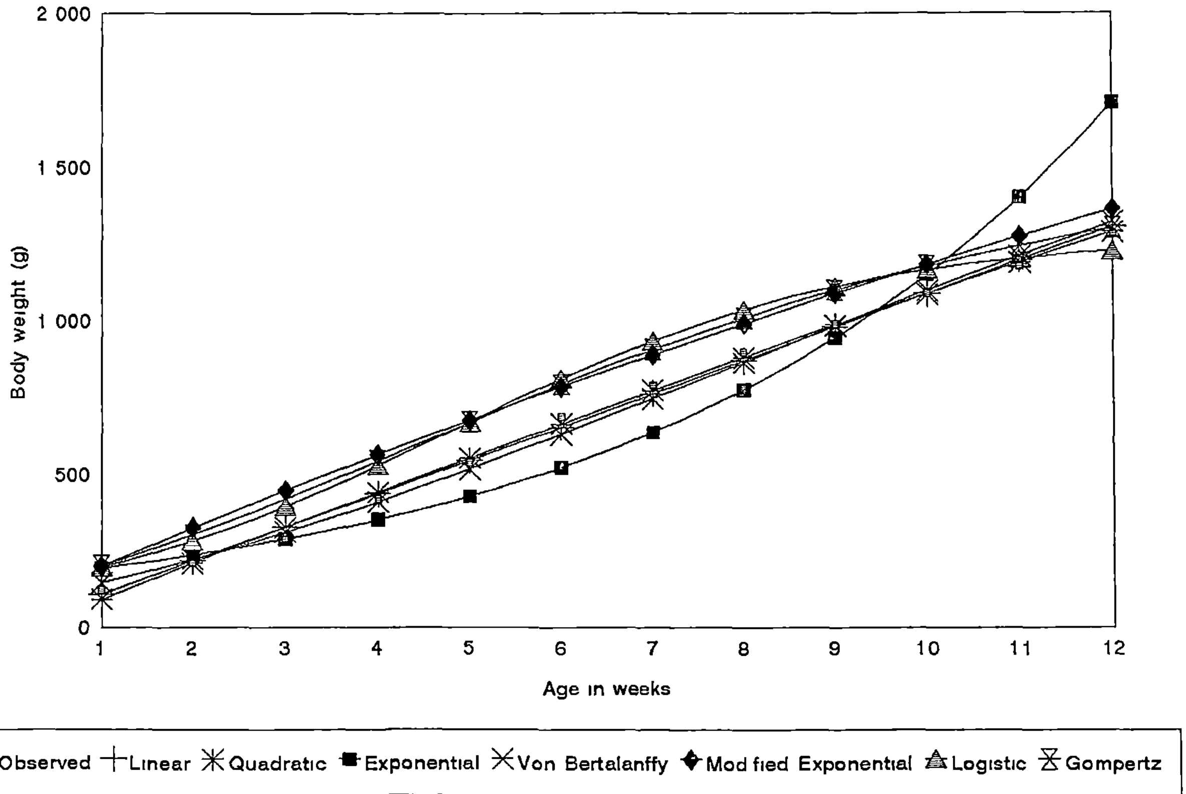


Fig 17 GROWTH MODELS FITTED TO BODY WEIGHTS OF SOVIET CHINCHILLA DURING THE PERIOD JUNE TO SEPTEMBER

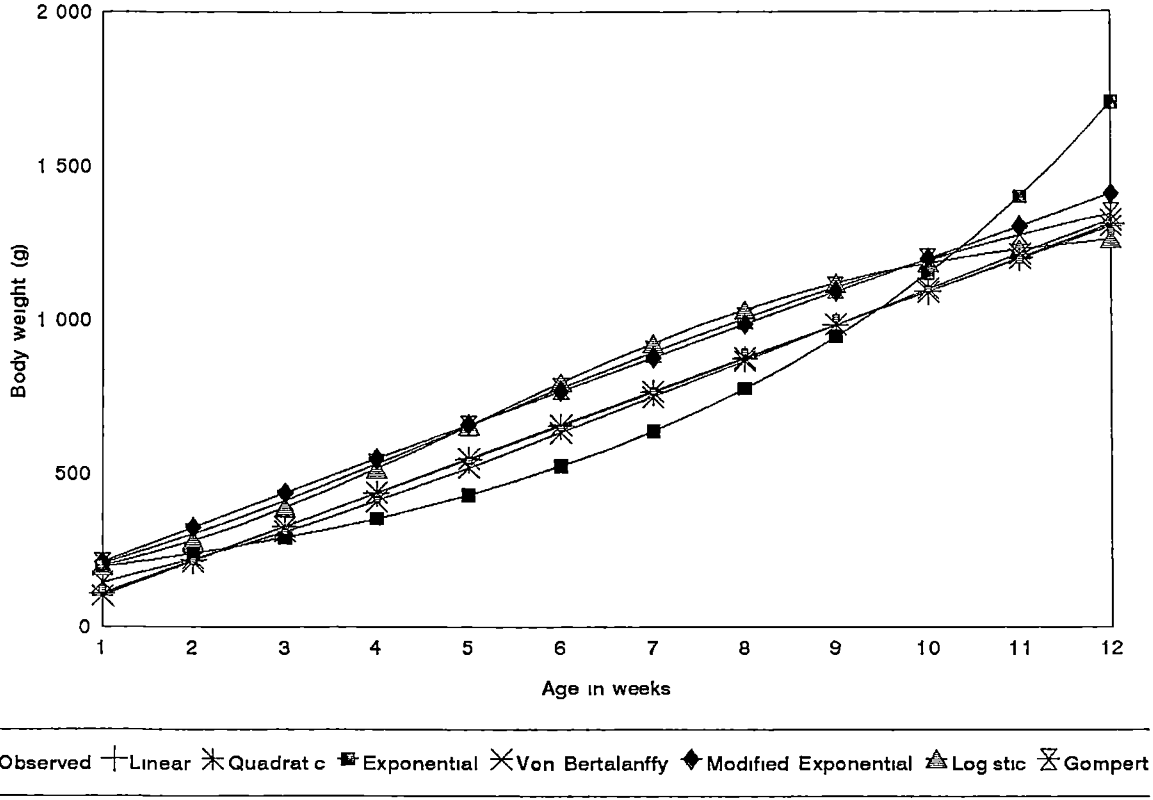
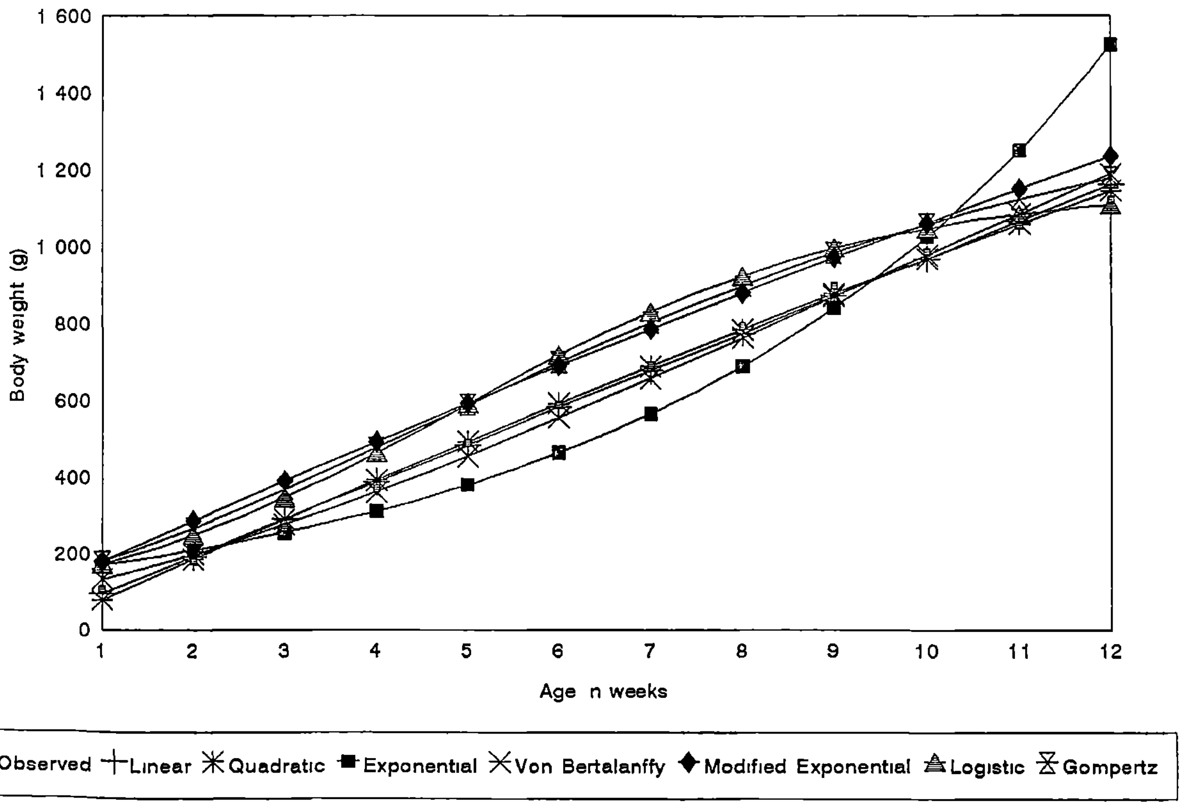


FIG 18 GROWTH MODELS FITTED TO BODY WEIGHTS OF GREY GIANT DURING THE PERIOD JUNE TO SEPTEMBER



Discussion

DISCUSSION

The results of the present investigation were already given in chapter 4 Most of the results obtained were having a reasonable comparison with the results obtained by other research workers in this field with some exceptions

In the case of climatological studies in rabbits practically no work have been done Hence could not have a comparative study of this aspect A discussion of the results obtained are given in this chapter

5 1 Average body weights

The average birth weight of Newzealand White in the first, second and third time periods (October to January February to May and June to September) were found to be 60 33 g 67 20 g and 65.38 g respectively These average birth weight obtained in all the three periods were higher than the average birth weight (59 68 g) reported by Mukundan *et al* (1993) For Soviet Chinchilla average birth weight for the first second and third time periods were 68 10 g 71 10 g and 52 90 g and that for Grey Giant were 71 20 g 70 00 g and 56 00 g respectively For Soviet Chinchilla average birth weights in the first and second time periods were higher than the weight (62 38 g) given by Mukundan *et al* (1993)

At the end of twelfth week the average body weights of Newzealand White were 1238 67±44 12g 1350 00±25.36g and 1238 39±46 60g for the first, second and third time periods respectively These estimates were higher than the mean body weight, 1005 6±29 2g reported by Radhakrishnan (1992) For Soviet Chinchilla the twelfth week body weights were 1301 18±39 91g 1298 64±25 36g and 1286 64±57 07g and that for Grey Giant were 1301 00±41 86g 1276 20±24 5g and 1122 88±47 90g respectively Radhakrishnan reported that the body weights at twelfth week of Soviet Chinchilla and Grey Giant were 1354 1±24 4g and 1226 1±27 1g respectively For Newzealand White and Soviet Chinchilla the average body weights obtained during all the three periods were lower than the body weights (1601 92±51 67g, 1544 29±62 08g respectively) given by Mukundan *et al* (1993)

Analysis of variance (Table 4) for effect of breed on body weight revealed that there was no significant difference in body weights of different breeds at all age except at first and fourth week during the first time period. During the second and third time periods there was no significant difference in body weights of different breeds (Tables 5 & 6) where as Radhakrishnan (1992) has shown significant difference for body weights in different breeds On observation it was found that Soviet Chinchilla and Grey Giant have higher body weights than that of Newzealand White during the first and second time periods During the third time period Newzealand White has higher body weight It is also clear from figures 1 to 9

Analysis of Variance (Tables 7 to 9) for effect of time periods on body weight within each breed revealed that periods exerted no significant effect on body weight at all age for Newzealand White and Soviet Chinchilla. But for Grey Giant there was significant difference in body weights between periods at all ages except at eighth week

5.2 Growth study through mathematical models

Out of the seven different mathematical models fitted it was observed that for the development of suitable models for ascertaining growth in rabbits using average body weights over twelve weeks von bertalanffy emerged as the best one followed by quadratic for Newzealand White (both female and rabbits irrespective of sex) Soviet Chinchilla and Grey Giant (male female and rabbits irrespective of sex) But for Newzealand White male quadratic emerged as the best followed by von bertalanffy

In general, von bertalanffy was found to be most suitable for ascertaining the growth pattern in the three breeds of rabbits viz Newzealand White Soviet Chinchilla and Grey Giant

Von bertalanffy curve fitted to the average body weights over twelve weeks were of the following form

For the first time period

New Zealand white male W_t = 2900 [1 0 7117 Exp(-0 0925t)]^3

New Zealand white female W_t = 2900 [1 0 7207 Exp(-0 0870t)]^3

New Zealand white irrespective of sex W_t = 2900 [1 0 7165 Exp(0 0918t)]^3

Soviet Chinchilla male W_t = 2860 [1 0 6759 Exp(0 0940t)]^3

Soviet Chinchilla female W_t = 2860 [1 0 6895 Exp(0 0918t)]^3

Grey Giant male W_t = 3000 [1 0 6690 Exp(-0 0867t)]^3

Grey Giant female W_t = 3000 [1 0 6630 Exp(-0 0875t)]^3

Grey Giant irrespective of sex W_t = 3000 [1 0 6660 Exp(0 0871t)]^3

For the second time period

New Zealand white male $W_t = 2900\ [\ 1 \quad 0\ 7117\ \mathrm{Exp}(\ 0\ 0925t)]^3$

New Zealand white female $W_t = 2900\ [\ 1 \quad 0\ 7207\ \mathrm{Exp}(-0\ 0870t)]^3$

New Zealand white irrespective of sex $W_t = 2900\ [\ 1 \quad 0\ 7165\ \mathrm{Exp}(\ 0\ 0918t)]^3$

Soviet Chinchilla male $W_t = 2860\ [\ 1 \quad 0\ 6759\ \mathrm{Exp}(-0\ 0940t)]^3$

Soviet Chinchilla female $W_t = 2860\ [\ 1 \quad 0\ 6895\ \mathrm{Exp}(\ 0\ 0918t)]^3$

Grey Giant male $W_t = 3000\ [\ 1 \quad 0\ 6690\ \mathrm{Exp}(-0\ 0867t)]^3$

Grey Giant female $W_t = 3000\ [\ 1 \quad 0\ 6630\ \mathrm{Exp}(-0\ 0875t)]^3$

Grey Giant irrespective of sex $W_t = 3000\ [\ 1 \quad 0\ 6660\ \mathrm{Exp}(\ 0\ 0871t)]^3$

For the third time period

New Zealand white male $W_t = 2900\ [\ 1 \quad 0\ 7117\ \mathrm{Exp}(\ 0\ 0925t)]^3$

New Zealand white female $W_t = 2900\ [\ 1 \quad 0\ 7207\ \mathrm{Exp}(-0\ 0870t)]^3$

New Zealand white irrespective of sex $W_t = 2900\ [\ 1 \quad 0\ 7165\ \mathrm{Exp}(\ 0\ 0918t)]^3$

Soviet Chinchilla male $W_t = 2860\ [\ 1 \quad 0\ 6759\ \mathrm{Exp}(-0\ 0940t)]^3$

Soviet Chinchilla female $W_t = 2860\ [\ 1 \quad 0\ 6895\ \mathrm{Exp}(\ 0\ 0918t)]^3$

Grey Giant male $W_t = 3000\ [\ 1 \quad 0\ 6690\ \mathrm{Exp}(\ 0\ 0867t)]^3$

Grey Giant female $W_t = 3000\ [\ 1 \quad 0\ 6630\ \mathrm{Exp}(\ 0\ 0875t)]^3$

Grey Giant irrespective of sex $W_t = 3000\ [\ 1 \quad 0\ 6660\ \mathrm{Exp}(-0\ 0871t)]^3$

The previous work done by Biggs (1959) showed that the growth model was a typical sigmoid curve which is also true in the present study

5.3 Relation between body weight, body length and body girth.

Among the two models namely additive and multiplicative models fitted for the three breeds multiplicative model emerged as the best one for developing a suitable relationship between body weight, body length and body girth with high value of R^2 and small value of s

New Zealand white $W_t = 0\,455\ L^{3\,13}\ G^{-0\,77}$ ($R^2 = 0\,99$ s = 1 09)

Soviet Chinchilla $W_t = 0\,139\ L^{0.54}\ G^{3\,22}$ ($R^2 = 0\,99$, s = 1 07)

Grey Giant $W_t = 0\,009\ L^{0\,75}\ G^{4.32}$ ($R^2 = 0\,99$ s = 1 11)

5 4 Climatological study

For the first time period, October to January the correlation coefficient between the average daily weight gain and THI (Temperature Humidity Index) was found to be significant and negatively correlated for all the three breeds In the second time period, February to May there was no significant correlation was found. But in the third time period, June to September significant positive correlation was obtained for all the three breeds It can be seen that from the table 20 during the first and third time periods temperature was comparatively low and humidity was comparatively high, but in the second time period the temperature was high and humidity was comparatively less Humidity was the highest in the third time period. With regards to body weight it was high in the second time period February to May in comparison to the first and third time periods Hence it can be concluded that high temperature with moderate humidity is congenial for the increase of body weight of rabbits A detailed study on climatological data will help us to get more reliable results

Summary

SUMMARY

With a view to develop suitable model for ascertaining growth in rabbits an experiment was conducted on October 1995 at the Kerala Agricultural University Rabbit Research Station Mannuthy The study was initiated using three different breeds of rabbit viz Newzealand White Soviet Chinchilla and Grey Giant The experiment consists of three parts each part was of duration four months as the broiler rabbit attains the marketable weight within a period around three months First time period October to January Second time period February to May and Third time period June to September

In each time period twenty numbers of one day old rabbits each of three breeds were kept under normal diet and uniform feed condition for a period of four months The body weights of these rabbits were recorded continuously up to twelve weeks The average birth weights of Newzealand White, Soviet Chinchilla and Grey Giant in the first time period were 60 33 g 68 10 g and 71 20 g respectively For the second time period the average birth weights were 67 20 g 71 10 g and 70 00 g and that for the third time period were 65 38 g 52 90 g and 56 00 g respectively

At the end of twelfth week the average body weights of Newzealand White Soviet Chinchilla and Grey Giant were recorded as 1238 67±44 12 g 1301 18±39 91 g and 1301 00±41 86 g respectively during the first time period. In the second time period the body weights for the three breeds were 1350 00±25 36 g 1298 64±25 36 g and 1276 20±24 5 g and those for the third time period were 1238 39±46 60 g 1286 64±57 07g and 1122 88±47 90 g respectively

Analysis of variance (ANOVA) was conducted for the body weights of three breeds which showed that there was no significant difference in body weights of the three breeds at all age in all the three periods except at first and fourth week of the first time period

ANOVA conducted for effect of time periods on body weight within each breed showed that there was no significant difference in body weights in the three time periods for Newzealand White and Soviet Chinchilla But in the case of Grey Giant there was significant difference in body weights between periods

Different mathematical models such as linear quadratic von bertalanffy exponential modified exponential logistic and gompertz were fitted and were compared using coefficient of determination (R^2) and standard error of estimate (s) values By comparison von bertalanffy model $W_t = a\ [1 \quad b\ Exp(kt)]^3$ was chosen as the best one for ascertaining growth in the three breeds of rabbits in all the three time periods

Body lengths body girths were also recorded over twelve weeks for three breeds Two models additive and multiplicative types fitted for finding the suitable relationship of body weight, body length and body girth multiplicative model $W_t = a\ L^b G^c$ where L is the body length and G' is the body girth emerged as the best one for the three breeds

Using the climatological data dry bulb temperature and wet bulb temperature Temperature Humidity Indices (THI) were calculated for twelve weeks during all the three time periods The correlation coefficients between THI and average daily weight gains per week were worked out. In the first time period a significant negative correlation obtained for Newzealand White Soviet Chinchilla and Grey Giant During the second time period no significant correlation was found. But in the third time period significant positive correlation obtained for all the three breeds

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STATISTICAL MODELS IN GROWTH STUDIES OF RABBIT

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ABSTRACT OF THE THESIS

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ABSTRACT

An investigation was undertaken in the Kerala Agricultural University Rabbit Research Station Mannuthy to find a suitable relationship between age and body weight of three different breeds of rabbit viz Newzealand White Soviet Chinchilla and Grey Giant and to study the impact of climatic elements temperature and humidity on body weight

The rabbits were reared under uniform feed formula and identical management practices The investigation mainly depended on data consisting of weekly body weights of rabbits up to twelve weeks and daily climatological parameters temperature and humidity The experiment was conducted during the three time periods (First time period October to January Second time period February to May and Third time period June to September)

Seven mathematical models such as linear quadratic von bertalanffy exponential modified exponential logistic and gompertz were fitted for body weights of individual rabbit as well as average body weights over twelve weeks and these models were compared using coefficient of determination (R^2) and standard error of estimate (s)

Additive model $W_t = a + b L + c G$ and Multiplicative model $W_t = a L^b G^c$ were fitted for developing a suitable relationship of average body weights body lengths and body girths over twelve weeks of the three breeds

Using the average weekly dry bulb temperature and wet bulb temperature Temperature Humidity Indices [$THI = 0\ 72\ (C_{db} + C_{wb}) + 40\ 6$] were worked out Correlation coefficients between average daily weight gain per week and THI were worked out for finding the effect of climatological data on body weight.

The investigation was having the following salient features

1 In the time period, October to January the body weight of Newzealand White is significantly different from that of Soviet Chinchilla and Grey Giant. New Zealand White has lower body weight But the difference in body weights between Soviet Chinchilla and Grey Giant was not significant In the second time period February to May and in the third time period June to September the difference in body weights of three breeds were not significant.

2 Von bertalanffy model $W_t = a\ [1\ \ b\ Exp(kt)]^3$ was the most suitable for ascertaining growth in the three breeds of rabbits on individual basis as well as on the basis of average body weights over twelve weeks

3 The multiplicative model $W_t = a\ L^b\ G^c$ was obtained as the suitable relationship of body weight body length and body girth of the three breeds of rabbit.

4 During the periods October to January (Winter) and June to September (Monsoon) temperature and humidity had significant effect on body weight. In the former period body weight will decrease along with increase in temperature and in the later period it will increase along with temperature