Data: ***Model and script***

Related to manuscript: *A mechanistic model to determine the energy expenditure for thermoregulation and critical temperature description in broiler chickens and laying hens*

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Fellow: Pos-doctoral

Abstract

The present document summarizes the model development and the code used, and this is part of the requirements of the scientific journal Animal, as a mandatory declaration of the model development accessible to reviewers and the community. The link to this repository will be available in the “Data and model availability statement” section of the manuscript "A mechanistic model to determine the energy expenditure for thermoregulation and critical temperature description in broiler chickens and laying hens". The model was developed by the post-doc Rony Riveros during their period on the Laboratory of Poultry Science of the São Paulo State University (LAVINESP), in the Campus of Jaboticabal.

1. Dataset used for model development

Dataset 1: Experiment of Broiler chickens			
Sources	Body weight, kg	Temperature, *C	Metabolic rate, kcal/d
Authors data	1.41	20	100
Authors data	1.46	25	102
Authors data	1.51	15	142
Authors data	1.44	30	115
Authors data	1.44	35	132
Authors data	1.40	20	91
Authors data	1.44	25	92
Authors data	1.44	15	120
Authors data	1.42	30	114
Authors data	1.45	35	122
Authors data	1.40	20	89
Authors data	1.38	25	88
Authors data	1.33	15	128
Authors data	1.37	30	127
Authors data	1.39	35	141
Authors data	1.48	20	103
Authors data	1.43	25	85
Authors data	1.48	15	131
Authors data	1.49	30	127
Authors data	1.49	35	127
Authors data	1.40	20	95
Authors data	1.46	25	91
Authors data	1.47	15	113
Authors data	1.40	30	119
Authors data	1.46	35	138
Authors data	1.51	22	92
Authors data	1.54	27	113
Authors data	1.50	22	97
Authors data	1.58	27	117
Authors data	1.49	27	99
Authors data	1.53	27	100
Authors data	1.52	22	120
Authors data	1.59	22	119
Authors data	1.53	32	113
Authors data	1.54	29	101
Authors data	1.51	29	100
Authors data	1.62	32	120
Koh & Macleod. 1999	1.13	14	197
Koh & Macleod. 1999	1.22	17	212
Koh & Macleod. 1999	1.19	22	183
Koh & Macleod. 1999	1.26	27	143

Koh & Macleod. 1999	1.24	32	133
Dixon and Teeter. 2003	0.55	16	50
Dixon and Teeter. 2003	0.88	16	60
Dixon and Teeter. 2003	1.35	16	78
Dixon and Teeter. 2003	2.00	16	99
Dixon and Teeter. 2003	0.55	22	62
Dixon and Teeter. 2003	0.88	22	63
Dixon and Teeter. 2003	1.35	22	73
Dixon and Teeter. 2003	2.00	22	86
Dixon and Teeter. 2003	0.55	32	41
Dixon and Teeter. 2003	0.88	32	54
Dixon and Teeter. 2003	1.35	32	72
Dixon and Teeter. 2003	2.00	32	88
Dixon and Teeter. 2003	0.93	22	75
Dixon and Teeter. 2003	2.28	22	120
Weirnusz & Teeter. 1993	1.50	24	150
Weirnusz & Teeter. 1993	1.50	24	160
Weirnusz & Teeter. 1993	1.50	24	166
Weirnusz & Teeter. 1993	1.50	24	185
Weirnusz & Teeter. 1993	1.50	33.5	154
Weirnusz & Teeter. 1993	1.50	33.5	172
Weirnusz & Teeter. 1993	1.50	33.5	188
Weirnusz & Teeter. 1993	1.50	33.5	188

Dataset 2: Experiment of laying hens			
Sources	Body weight, kg	Temperature, *C	Metabolic rate, kcal/d
Authors data	1.41	20	100
Authors data	1.46	25	102
Authors data	1.51	15	142
Authors data	1.44	30	115
Authors data	1.44	35	132
Authors data	1.40	20	91
Authors data	1.44	25	92
Authors data	1.44	15	120
Authors data	1.42	30	114
Authors data	1.45	35	122
Authors data	1.40	20	89
Authors data	1.38	25	88
Authors data	1.33	15	128
Authors data	1.37	30	127
Authors data	1.39	35	141
Authors data	1.48	20	103
Authors data	1.43	25	85
Authors data	1.48	15	131
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Authors data	1.46	25	91
Authors data	1.47	15	113
Authors data	1.40	30	119
Authors data	1.46	35	138
Authors data	1.51	22	92
Authors data	1.54	27	113
Authors data	1.50	22	97
Authors data	1.58	27	117
Authors data	1.49	27	99
Authors data	1.53	27	100
Authors data	1.52	22	120
Authors data	1.59	22	119
Authors data	1.53	32	113
Authors data	1.54	29	101
Authors data	1.51	29	100
Authors data	1.62	32	120
Dixon and Teeter. 2003	2.70	16	120
Dixon and Teeter. 2004	2.97	16	172
Dixon and Teeter. 2005	3.18	16	154
Dixon and Teeter. 2006	3.32	16	175
Dixon and Teeter. 2007	3.50	16	159
Dixon and Teeter. 2008	2.70	22	119
Dixon and Teeter. 2009	2.97	22	138
Dixon and Teeter. 2010	3.18	22	144
Dixon and Teeter. 2011	3.32	22	153
Dixon and Teeter. 2012	3.50	22	178
Dixon and Teeter. 2013	2.70	32	127
Dixon and Teeter. 2014	2.97	32	119
Dixon and Teeter. 2015	3.18	32	121
Dixon and Teeter. 2016	3.32	32	144
Li et al. 1992	3.50	32	136
Li et al. 1992	1.53	36	140
Li et al. 1992	1.53	32	144
Li et al. 1992	1.53	24	162
Li et al. 1992	1.53	28	167
Li et al. 1992	1.53	20	172
Li et al. 1992	1.53	16	173

2. Theoretical model development

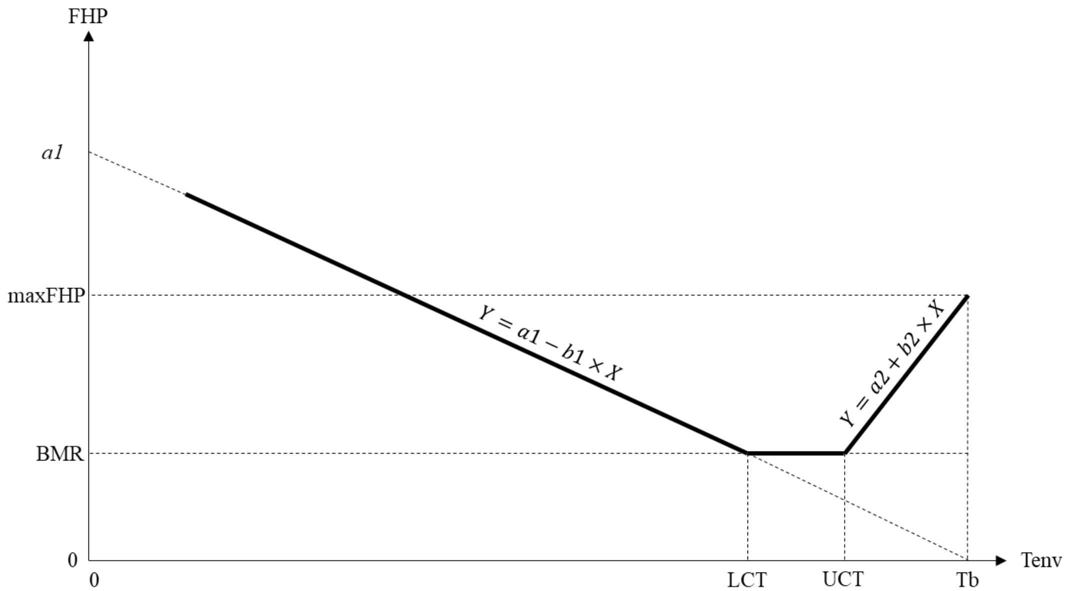

Figure 1. Description of the three-segmented model to define the lower and upper critical temperatures and define the range for thermoneutral zone determination in adult chickens (laying hens).

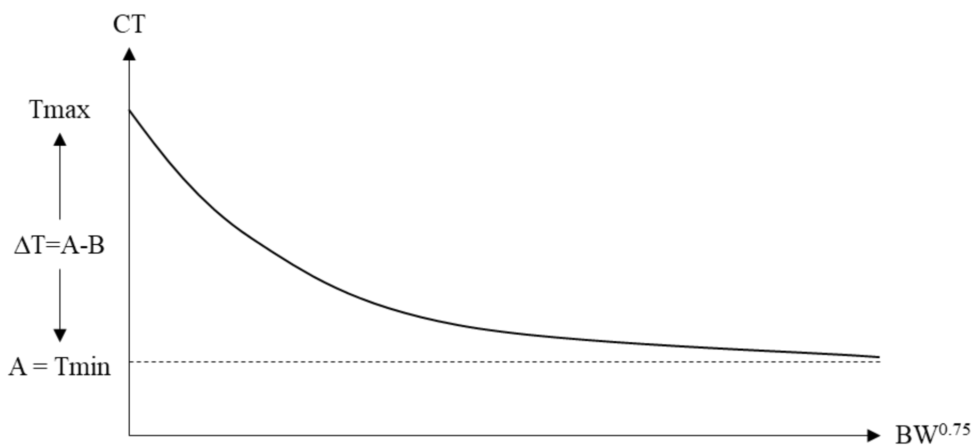

Figure 2. Non-linear function to describe the critical temperature variation as a function of the metabolic body weight in broiler chickens.

3. **Step-by-step model development-integration**

1st Function for Tenv below TNZ (cold conditions)

It is a decreasing linear regression:

$$Y = a1 - b1 \times X$$

Where ***a1*** is the intercept and ***b1*** is the rate of decrease in the metabolic rate as a function of ***X*** (Tenv).

The first condition is that the minimum ***Y*** value is the ***BMR***, and the intercept on the X-axis is ***Tb***. In this sense:

$$\frac{\Delta Y}{\Delta X} = b1 = \frac{BMR - 0}{Tb - CT}$$

To calculate the intercept ***a1***, it can be replaced by:

$$\frac{a1 - BMR}{CT} = \frac{BMR}{Tb - CT}$$

Solving this equivalence, and isolating ***a1***:

$$a1 = BMR \times \frac{Tb}{Tb - CT}$$

Finally, the function is:

$$Y = BMR \times \frac{Tb}{Tb - CT} - \frac{BMR}{Tb - CT} \times X$$

Simplifying:

$$Y = BMR \times \frac{Tb - X}{Tb - CT} = BMR \times \frac{\Delta T_{actual}}{\Delta T_{desired}}$$

In this function, Δ***T*** represents the gradient of temperatures, and represents the correction of basal energy expended as a function of the temperature.

2nd Function for Tenv above TNZ (heat condition)

It is an increasing linear function

$$Y = a2 + b2 \times X$$

Where ***a2*** is the intercept and ***b2*** is the rate of increase in the metabolic rate as a function of the ***Tenv***.

Assuming that when ***Tenv***=***Tb*** (which is not biologically possible, the heat transfer between the animal and the environment), then ***Y***=***maxFHP***:

$$\frac{\Delta Y}{\Delta X} = b2 = \frac{maxFHP - BMR}{Tb - CT}$$

Additionally, when considering ***a2*** as intercept when ***X***=0:

$$\frac{BMR - a2}{CT} = \frac{maxFHP - BMR}{Tb - CT}$$

Isolating ***a2*** in the equation:

$$a2 = BMR - (maxFHP - BMR) \times \frac{CT}{Tb - CT}$$

Replacing the linear regression function:

$$Y = BMR - (maxFHP - BMR) \times \frac{CT}{Tb - CT} + (maxFHP - BMR) \times \frac{X}{Tb - CT}$$

Simplifying the function:

$$Y = BMR + (maxFHP - BMR) \times \frac{X - CT}{Tb - CT} = BMR + (maxFHP - BMR) \times \frac{\Delta T_{actual}}{\Delta T_{desired}}$$

For temperatures above ***CT***, the ***BMR*** is corrected by an additional energy term that depends on the difference between the minimum energy required (***BMR***) and the maximum energy expended before death (***maxFHP***), and it is relative to the environmental temperature.

3rd Function for Tenv between lower and upper CT

When lower and upper CT differ (it is possible to evidence a range between both), a single function is described:

$$Y = BMR; LCT <> UCT$$

4. SAS Code

```
*Code for Trail 1;
proc nlmixed data=data method=gauss tech=newrap maxiter=200 maxfunc=1000
            qpoints=5;
      parameters BMR=90 A=15 B=5 k=0.04 p=70 q=30 s2e=1;

      /* Define intermediate calculations */
      CT=A + (A - B) * EXP(-k * BW**0.75);
      maxFHP=p + q * BW**0.75;
      Tb=40.2+0.042*T;

      /* Ensure maxFHP is always greater than BMR */
      if maxFHP <=BMR then
            maxFHP=BMR + 0.1;

      /* Define Z based on temperature conditions */
      if T < CT then
            Z=BMR * (Tb - T) / (Tb - CT);
      else
            Z=BMR + (maxFHP - BMR) * ((T - CT) / (Tb - CT));

      /* Model specification */
      model FHP_MBW ~ normal(Z, sqrt(s2e));
      ods output FitStatistics=fit_stats ParameterEstimates=param_ests;
run;

*Code for Trail 2;
proc nlmixed data=data;
      /* Define parameters */
      parameters BMR=90 maxFHP=150 UCT=24 LCT=22 s2e=1;

      /* Define Tb */
      Tb=40.2 + 0.042 * T;

      /* Define Z based on temperature conditions */
      if T <=LCT then
            Z=BMR * (Tb - T) / (Tb - LCT);
      else if LCT < T <=UCT then
            Z=BMR;
      else if T > UCT then
            Z=BMR + (maxFHP - BMR) * ((T - UCT) / (Tb - UCT));

      /* Model specification */
      model FHP ~ normal(Z, sqrt(s2e));

      /* Random effect (if needed) */
      *random u ~ normal(0, su) subject=Age;

      /* Output predicted values */
```

```
    predict Z out=predicted_values;

    /* Capture fit statistics and parameter estimates */
    ods output FitStatistics=fit_stats ParameterEstimates=param_ests;
run;
```